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Edited for the Council by J. LAURENCE PRITCHARD, Honorary Fellow

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NOTICES

Elections

The following members were elected at a Council Meeting held on April 15th:—

Associate Fellows.—Wing Commander H. M. Cave-Browne-Cave, D.S.O., D.F.C., Mr. H. Akroyd Stuart, Mr. G. R. Volkert and Mr. D. L. H. Williams.

Students.—Mr. A. A. Hammond and Mr. L. A. Lansdown.

Foreign Members.—Mr. A. Matsomoto and Mr. A. C. von Baumhauer.

Associate Member.—Mr. M. Miyata.

Council

The full Council for the year 1924-1925 is as follows:—Professor L. Bairstow, Major-General Sir W. S. Brancker, Mr. Griffith Brewer, Wing Commander T. R. Cave-Browne-Cave, Sir Mackenzie Chalmers, Mr. C. R. Fairey, Professor C. F. Jenkin, Major A. R. Low, Mr. W. O. Manning, Lieut.-Colonel J. T. C. Moore-Brabazon, Mr. J. D. North, Lieut.-Colonel A. Ogilvie, Lieut.-Colonel M. O'Gorman, Mr. J. L. Pritchard, Colonel the Master of Sempill, Sir Napier Shaw, Major R. V. Southwell, Lieut.-Colonel H. T. Tizard, Major H. E. Wimperis and Mr. R. McKinnon Wood with Mr. A. E. Turner (Honorary Treasurer).

Foreign Societies

Arrangements have been made with the Aéro Club de France for members of the Society to become temporary members for a period of 15 days and to use the Club's rooms while in Paris. Temporary membership cards may be obtained on application to the Secrétaire-Général, Aéro Club de France, 35, Rue François 1er, Champs Elysées, Paris (VIIIe).

Similar arrangements have been made with the Société Française de Navigation Aérienne, Hôtel de la Société des Ingénieurs Civils de France, 19, Rue Blanche, Paris (IXe), for members of the Society to attend lectures and consult books in the library.

Scottish Branch

The Duke of Sutherland has joined the Executive Committee of the Scottish Branch, which has moved to 196, St. Vincent Street, Glasgow.

XIIM

Donations

The Council desire to thank Lady Maxim for kindly presenting the following further volumes from the library of the late Sir Hiram Maxim:—"Aerial Navigation," by J. G. W. Fijne; "My Life and Balloon Experiences," by H. Coxwell; "Navigation Aérienne," by G. Tissandier; "Aircraft in Warfare," by F. W. Lanchester; and "Parakites," by G. T. Woglom.

Wilbur Wright Lecture

Lieutenant-Colonel H. T. Tizard, A.F.C., Fellow, has accepted the Council's invitation to deliver the Wilbur Wright Memorial Lecture, which will take place at **8.30 p.m.** on Thursday, May 29th, at the Royal Society of Arts, John Street, Adelphi, the subject being "Fuel Economy in Flight."

W. Lockwood Marsh, *Secretary.*

PROCEEDINGS

SEVENTH MEETING, 59TH SESSION

A meeting of the Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, January 24th, 1924, the Chairman, Colonel A. Ogilvie, presiding.

The CHAIRMAN, in opening the proceedings, said the lecturer that evening was Dr. J. E. Ramsbottom, who had been working on dopes at the Royal Aircraft Establishment at Farnborough for about ten years, and who would give the members the benefit of his experience and the results of his tests in a form which they would find interesting. He called upon Dr. Ramsbottom to read his paper, as follows:—

DOPES AND FABRIC

In this paper it is proposed to deal with dopes and fabric as far as they relate to the problem of the production of a structural covering for aircraft which will maintain its tautness under varying conditions of humidity and also retain its strength after prolonged weathering.

It is convenient to divide the subject matter into two main sections:—

1. Tautness.
2. Strength.

I TAUTNESS

The method generally used at the R.A.E. for determining the tautness of doped fabric is to place a sphere loaded with a known weight on the centre of the fabric which is firmly fixed on rigid frames of standard dimensions and to measure the consequent depressions. The figures obtained are approximately inversely proportional to the tautness.* Photo A shows the apparatus generally used.

A—General Effect of Humidity on Tautness

The application of six coats of standard dope B.E.S.A. to aero fabric F.I. stretched on a frame at the usual tensions (2 lbs. per in. warp and 1 lb. per in. weft) produces when dry a surface which is reasonably taut at normal humidities. The tautness, however, is affected by changes in the humidity of the atmosphere. This is shown in Fig. 1a, which gives the tautness of a frame of doped fabric on different days, the corresponding humidity at the time of measurement being also shown.

When such a frame of doped fabric is brought from an atmosphere of low humidity to one nearly saturated, a rapid loss of tautness is first observed. After a time, however, the doped fabric begins to tauten and continues to do so until equilibrium is reached. Fig. 1b helps to explain this behaviour. It shows the change in tautness of dope film, fabric and doped fabric respectively when dry and after exposure for various periods to an atmosphere of 95 per cent. humidity.

* In practice it is the amount of deformation of the wing surface during flight which is important; hence in this paper depressions and not their reciprocals are given.

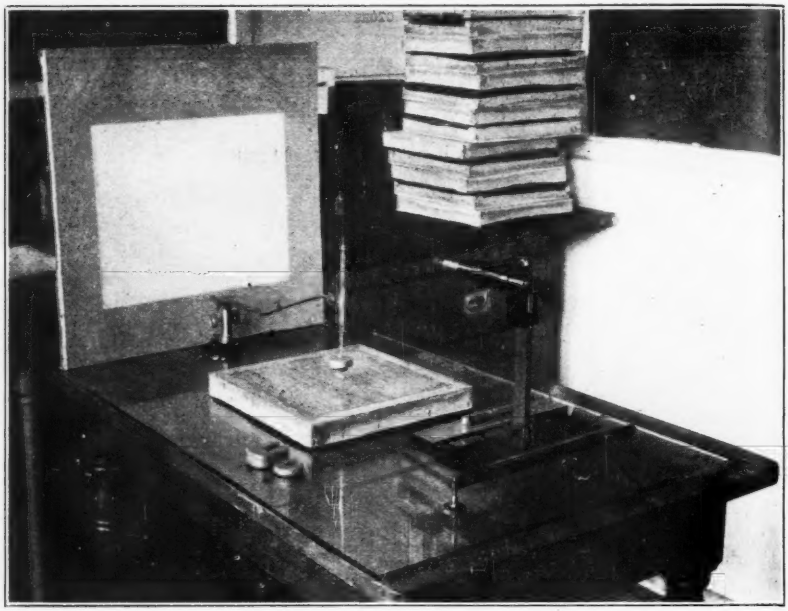
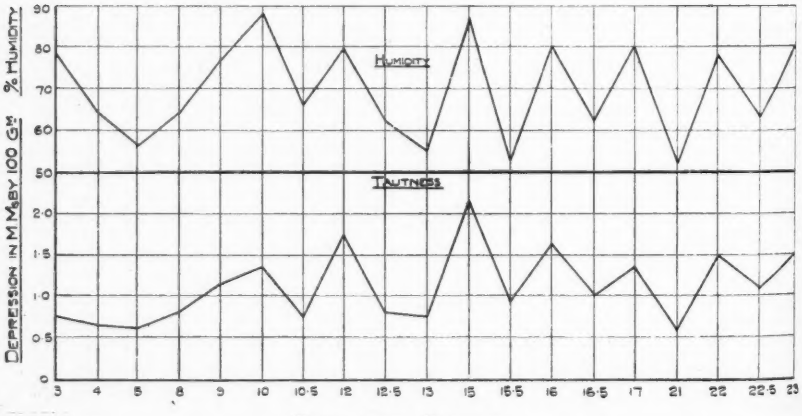


Photo A.

General Effect of Humidity on Tautness.

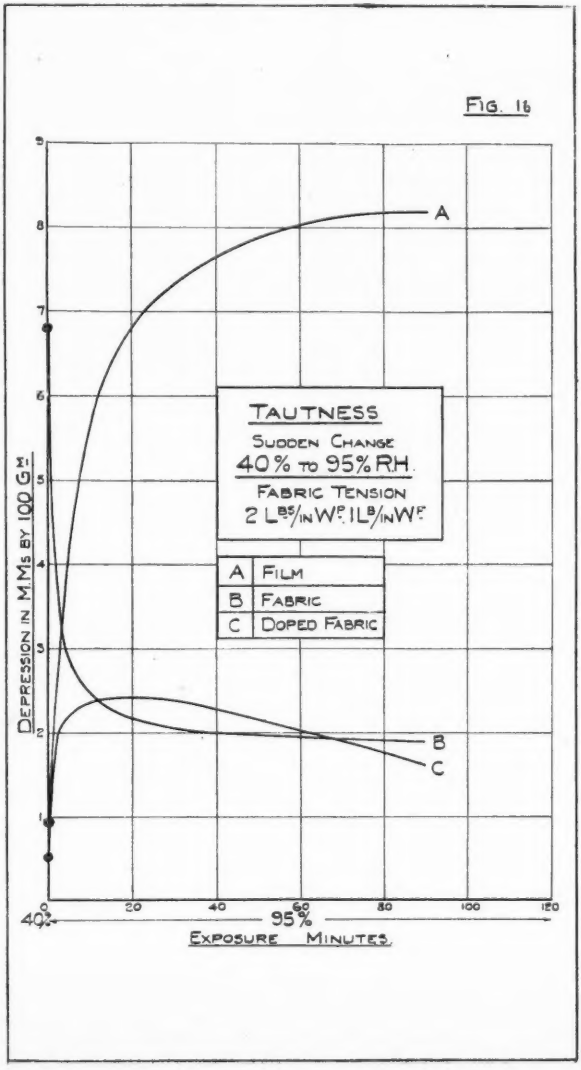


Days after Doping.

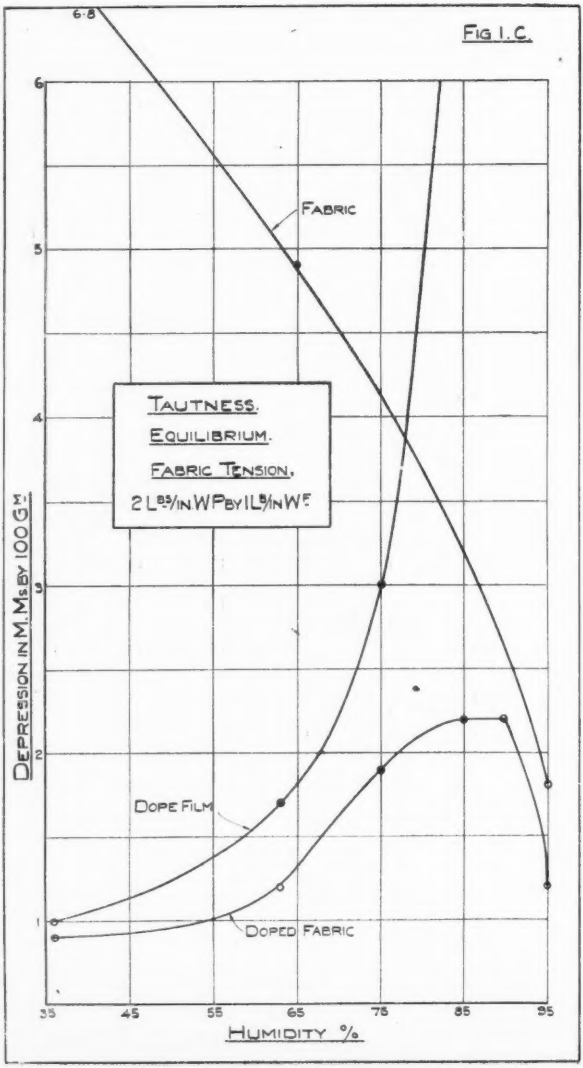
Fig. 1A.

The dope film loses tautness with increasing humidity while the tautness of the fabric increases.

It is evident that the dope is primarily responsible for the tautness of doped fabric at low humidities and that the falling off in tautness as the humidity increases is due to loss in tautening power of the dope. This falling off continues until the tautening effect of fabric and dope are approximately equal, after which the tautness is apparently dominated by the fabric and increases as the fabric further contracts. Assuming the film and fabric in the combination had no influence on each other, it would be expected that the minimum tautness would occur at the



point at which the dope film and fabric curves cross, and that from this point until equilibrium is reached the tautness curve of the doped fabric would coincide with that of the fabric. Actually the minimum does not occur until after a considerably longer exposure to a moist atmosphere, and from this point the tautness of the combination is a little less than that of the fabric alone until equilibrium is approaching, when the order is reversed. This is to be expected since by uniting the dope film and fabric the exposed surface of each is reduced and hence also the rate of absorption of moisture. The slope of both curves is thus lessened and the point of intersection moved to the right. Further, in the combination the dope



and fabric assist each other in resisting depression, and so apart from humidity the tautness of the doped fabric will be greater than either of its components, as is clearly seen when equilibrium is approaching. Further experiments, in which the specimens were kept for fifteen hours at definite humidities, indicate that the peak in the tautness-humidity curve—representing the point at which the tautening actions of dope and fabric are equal—occurs at about 80 per cent. to 90 per cent. R.H. for fabric at the usual tension when equilibrium is established. On weathering doped fabric there is a progressive falling off in tautness. At low humidities the loss is slight, but becomes more marked as the humidity increases. The maximum depression obtained on transference from a dry to a nearly saturated atmosphere becomes progressively greater on weathering.

TABLE I.

	Depressions m.m. 400 g.		
Age (days).	% Humidity 45.	Sudden change 45 to 90.	90.
5	2.2	3.1	2.0
150	2.6	4.3	3.8
300	2.9	6.8	6.2

Fig. 2 gives the comparative rates of moisture absorption of film fabric and doped fabric.

B—Effect of Temperature

The tautness of doped fabric is influenced to a small extent by temperature. Tests carried out in a chamber, the temperature and humidity of which could be kept constant for long periods, gave the following tautness results. Linen fabric doped with pigmented acetyl dope and V.84 was used.

TABLE II.

	Depressions m.m. 400 g.	
% humidity.	30	80
Temperature 5°C.	3.1	4.4
18°C.	3.5	4.8

Slightly better tautness results were obtained at the lower temperature. In addition it was found that the time required to reach the equilibrium point was considerably longer at the lower temperature.

C—Fabric

(a) Nature and Structure

Experiments carried out with linen, cotton and silk fabrics of various weights and degrees of fineness of yarn, the fabrics being stretched on frames under a tension of 2 lbs. per in. warp and 1 lb. per in. weft, have led to the following general conclusions. Linen and cotton behave similarly with respect to tautness changes under varying humidity conditions. Silk compares unfavourably with linen and cotton. On subjecting doped silk to a high humidity, the tautness falls

off continuously; there is no indication of a tautening influence of the fabric such as occurs with linen and cotton. This is not surprising in view of the observation that undoped silk stretched on a frame and exposed to a high humidity was found to slacken continuously until equilibrium was attained, in contrast to linen and cotton, which tauten with increasing humidity (Fig. 3). Mercerised cotton shows a greater response to humidity changes than linen or cotton, which accounts for the good tautness results obtained with this material at high humidities. The

RATE OF ABSORPTION OF WATER BY FABRIC, DOPE FILM AND DOPED FABRIC.

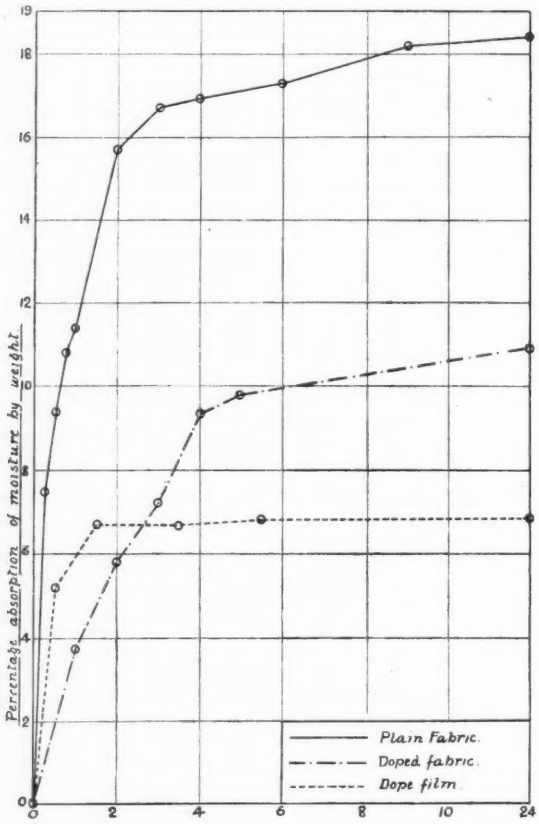


FIG. 2.

difference in behaviour of doped silk and linen fabric when brought from a dry to a moist atmosphere is shown in Fig. 4. In general, fabrics made from fine yarns retain their tautness on weathering better than the coarser varieties. This may possibly be explained by the greater slackening which was found to occur with coarse yarns taken singly when wetted under tension and allowed to dry.

Closeness of weave is important. If the fabric is too coarse excessive penetration takes place and dope is wasted.

The best tautness results have been obtained with closely-woven highly-calendered fabric, indicating that the adhesion is satisfactory even when the dope penetration is small.

All the cases of alleged poor adhesion we have investigated have been due to excessively thick dope films or to the use of an unsuitable dope, or to impurities in the fabric.

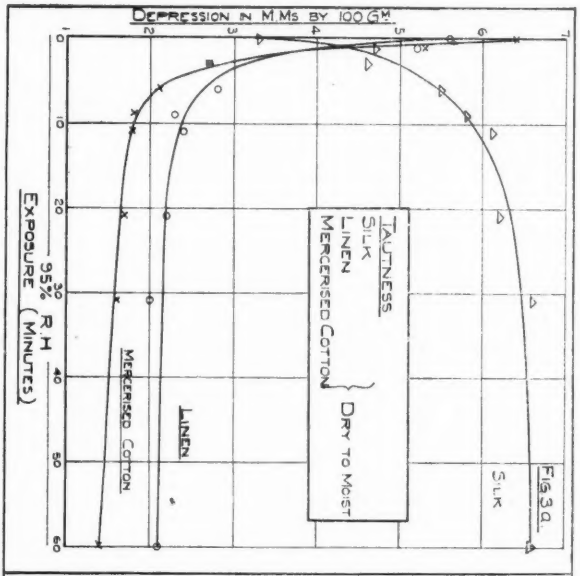


Fig. 3a.

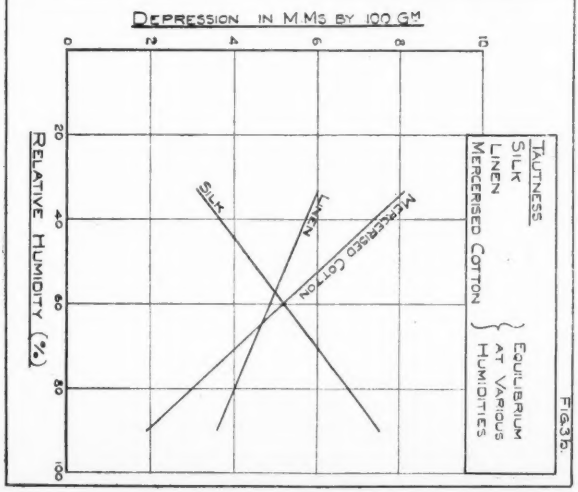


Fig. 3b.

(b) Initial Tension

The initial tension at which the fabric is stretched on the framework before dope is applied is important since the tension in the fabric appears to determine the tautness at high humidities.

Cases of slack planes in service have been traced to the practice of covering them with fabric some considerable time before the dope is applied, the fabric in the meantime having lost practically all its tension. Fabric put on frames at standard tension soon loses a greater part of this, even if the humidity is kept constant.

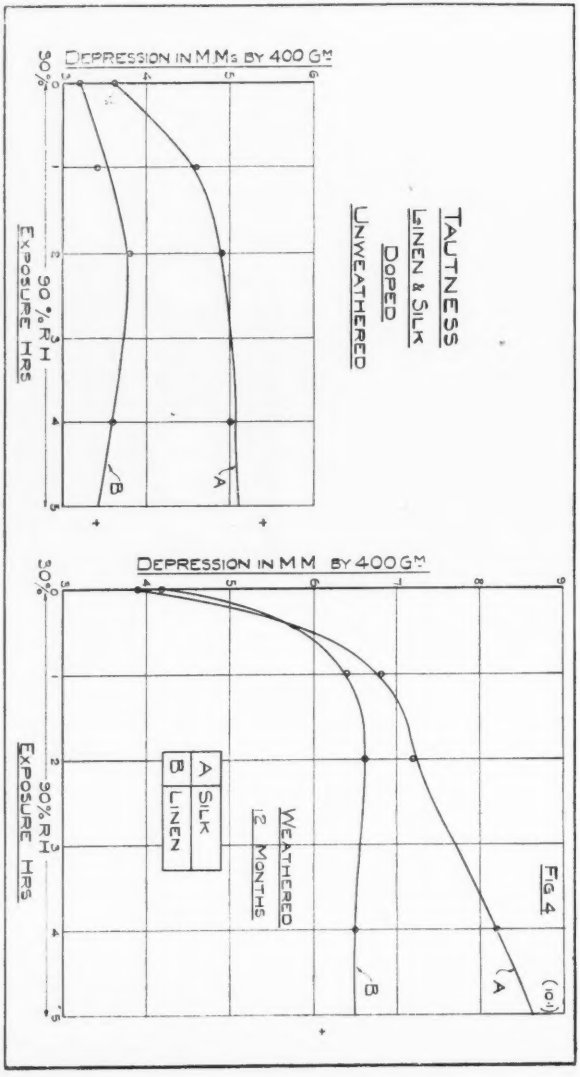


FIG. 4

The influence of initial tension in the fabric is shown in Fig. 5. The frames were covered with fabric under tensions of :—

A. *Nil.*

B. 2 lbs. per in. warp and weft.

C. 5 lbs. per in. warp and weft.

by means of the apparatus shown in Photo B.

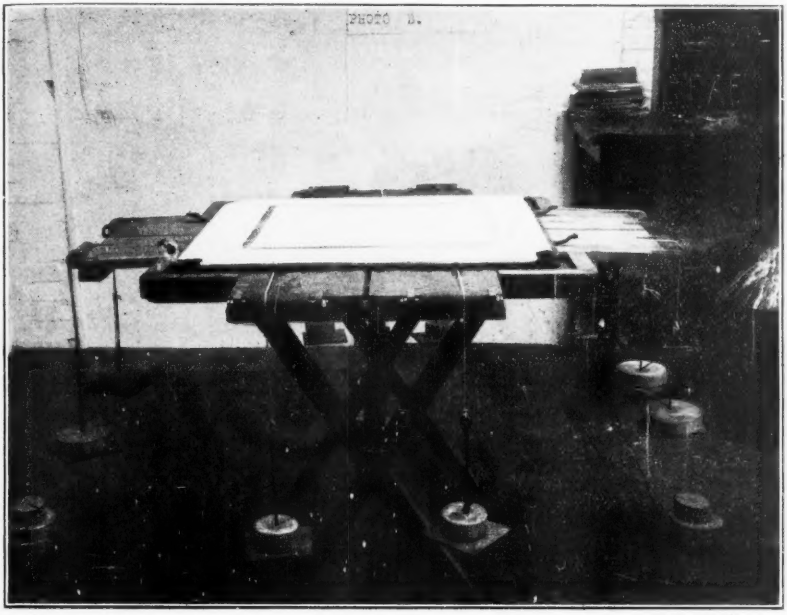


FIG. B.—*Testing tensions of fabric.*

They were treated with standard acetyl dope. The greater the initial tension of the fabric at any rate up to 5 lbs. per in. the better the tautness of the covering at high humidities. The effect is more marked after weathering.

Another series of tests was carried out at two of these tensions, but the frames were kept for fifteen hours at definite humidities so as to attain equilibrium before the tautness measurement was made.

At low humidities there was no difference in tautness. At high humidities the loss in tautness in the case of fabric put on at 5 lbs. was considerably less than that of fabric at the lower tension; the minimum tautness regions occurred at about 65 per cent. R.H. and 85 per cent. R.H. respectively (Fig. 6).

In a third series of tests at tensions of 5lbs., 2 lbs. and ½ lb. respectively, the tautness was measured after each coat (R.H. about 20 per cent.). With the fabric at 5 lbs. tension the first coat of dope caused a falling off in tautness. After the third coat all the specimens had attained the same degree of tautness (Fig. 6A).

The humidity condition of the fabric when stretched on the framework is

important. Fabric kept at a humidity of 65 per cent. and stretched at this humidity gave tautness results inferior to those obtained with fabric at a humidity of 35 per cent. (Fig. 6B).

It is probable that in practice the tensions obtained in the fabric by hand-stretching do not generally exceed 2 lbs. per in. warp and 1 lb. per in. weft. As the contractile power of dope may reach the order of 4 lbs. to 7 lbs. per in., it seems safe to assume that greater tensions could be put in the fabric without distortion of the framework.

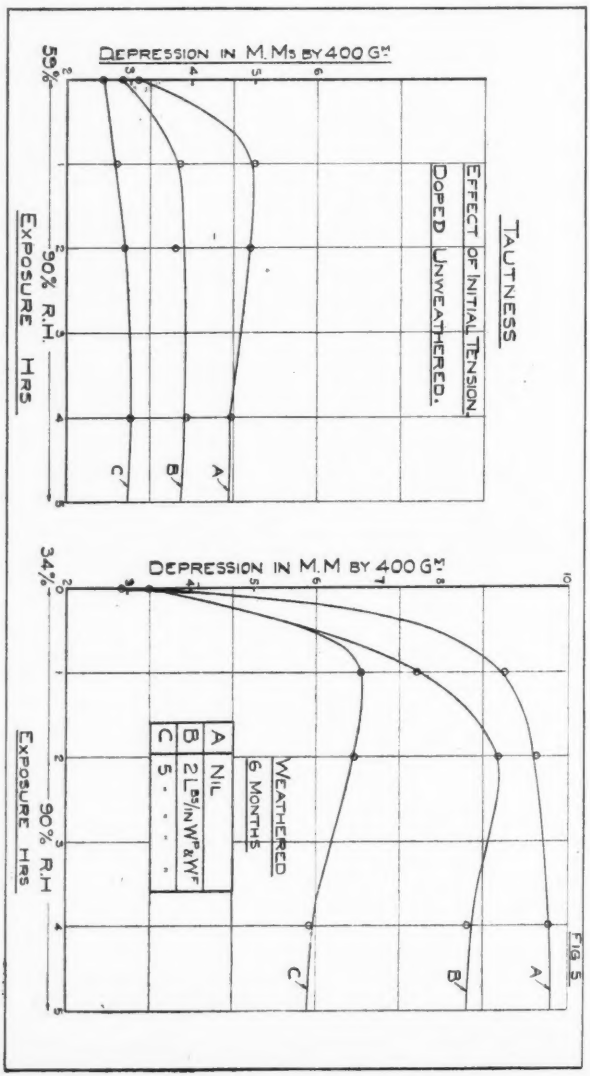
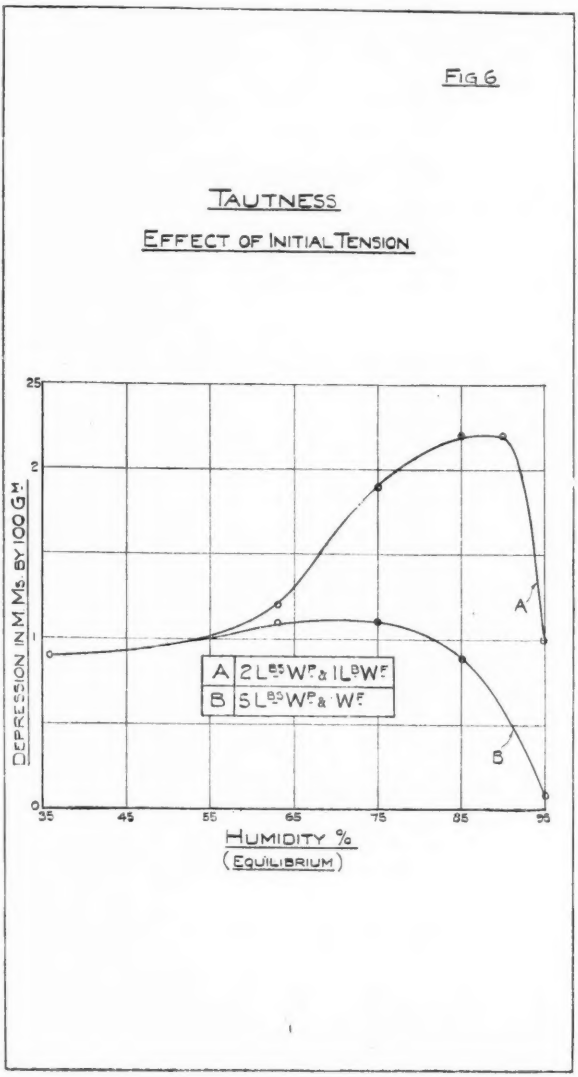


FIG. 5

(c) Extensibility

The tautness of doped fabric at high humidities depends not only on the initial tension at which the fabric is put on the framework, but also on its extensibility at low loads. Some of the early cotton fabrics used on aircraft were unsatisfactory because of their large extensibility.



To determine the effect of the removal of some of the "potential stretch" of the fabric before fixing it to the framework, experiments were carried out on frames covered with fabric stressed as follows:—

Frame.	Tension lbs. per in.	Time stressed, hours.	
A.	2	1	Dry.
B.	5	20	Wet with water, dried under tension but fixed at 2 lbs.
C.	5	20	Wet with water, dried and fixed under tension.

The results are shown in Fig. 7.

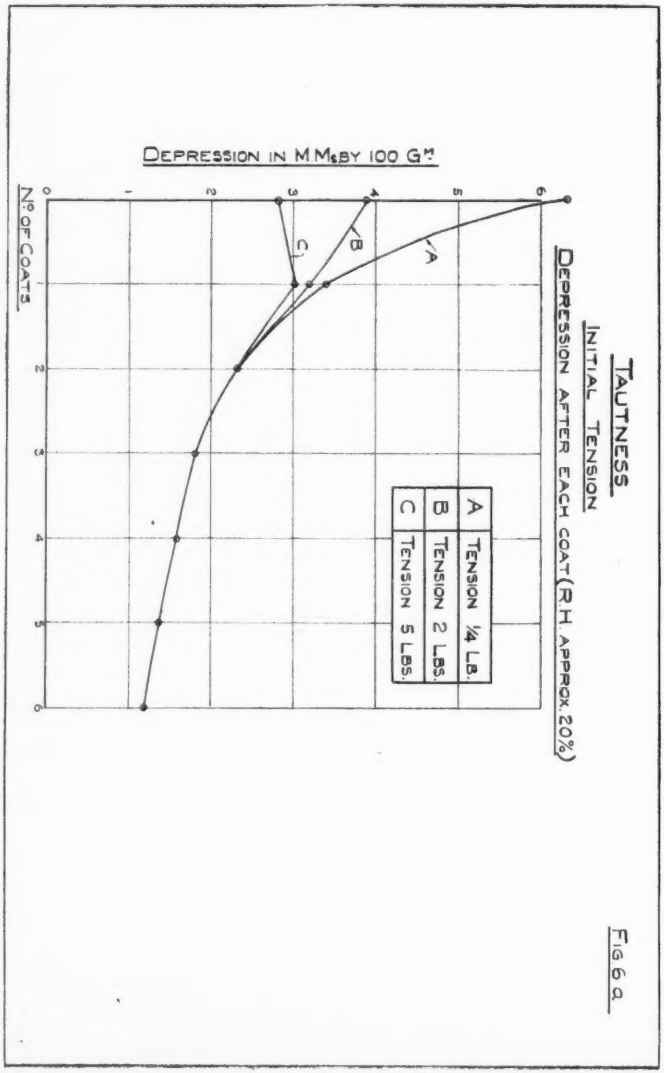


FIG 6a.

Stressing the fabric wet at 5 lbs. results in a much tauter covering at high humidities. The advantage is retained to a large extent even after weathering twelve months. The improvement is still considerable when the fabric is stressed at 5 lbs. while wet and then fixed at the usual tension of 2 lbs.

D—Dope

The maximum degree of tautness which can be obtained with a doped fabric appears to be governed by the composition of the dope. Much greater tensions in the fabric can be obtained mechanically than those induced by the dope, but these high tensions are not long retained, the elastic limit of the dope being the deciding factor. The tautening power of nitro and acetyl cellulose can be readily

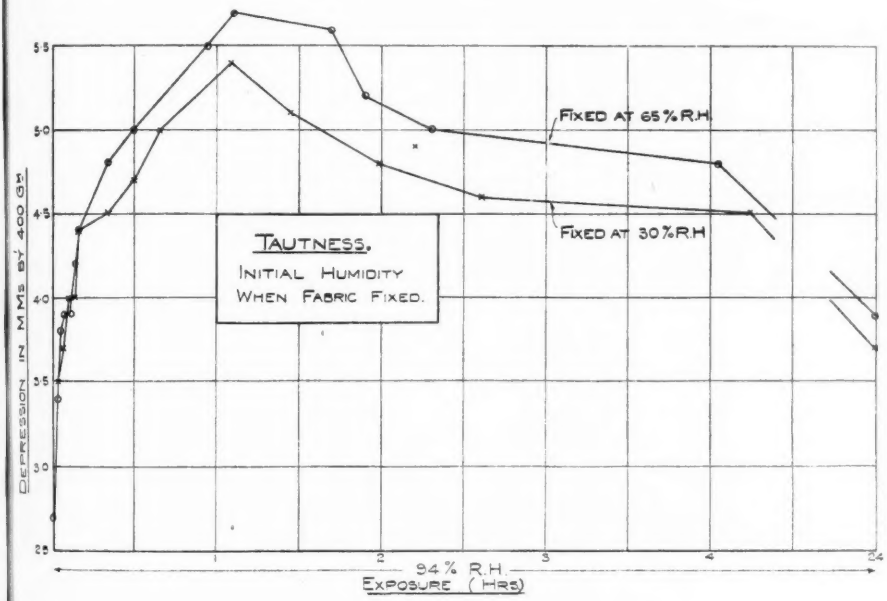


FIG. 6B.

modified by the use of so-called softeners to give tensions from *nil* to the order of approximately 9 lbs. per in. Barr, who has devised a direct measuring apparatus, gives the maximum tension of standard acetyl dope and P.C.10 as about 6 lbs. per in.

Both acetyl and nitro-cellulose dope films absorb moisture, and the consequent expansion and loss of elasticity results in a falling off in tautness of the covering when exposed to a moist atmosphere.

This defect can be remedied to some extent by introducing waterproofing softeners into the dope. One of the most effective of these is triphenyl phosphate. Table III. shows the rate of absorption of moisture by cellulose acetate films when dried and placed in an atmosphere of approximately 95 per cent. R.H.

A. Without triphenyl phosphate.

B. Containing 13 per cent. by weight triphenyl phosphate. Thickness of films, .16 m.m. Age, 26 days.

TABLE III.

Time—hours.	% Increase in weight.	
	A.	B.
½	4·9	1.8
1	6.2	2.7
2	7·7	3.8
4	9.1	4·7
6	9·9	5·4
18	10.4	6.2

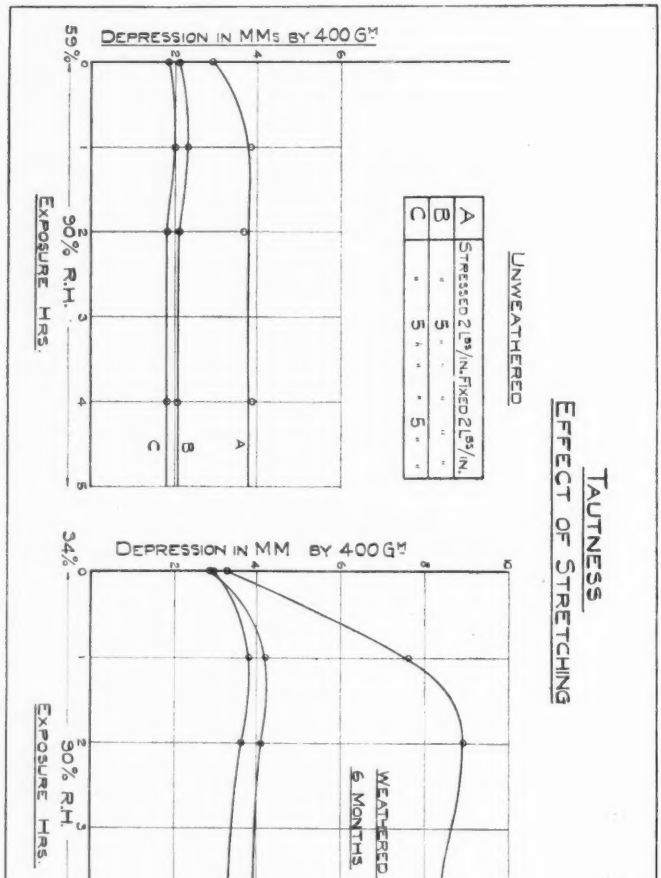


FIG. 7

A corresponding difference in tautness at varying humidities is observed when the dopes are applied to fabric.

Such softeners, besides affecting the water absorption of the film, also reduce the tautening power so that the amount which can be added is limited.

So far we have not succeeded in obtaining a satisfactory cellulose acetate film as resistant to moisture as a nitro-cellulose film.

(a) Pigmentation of Dopes

A further improvement toward the attainment of a wing covering of uniform tautness at varying humidities is effected by the introduction of pigments into a cellulose ester dope. Pigmented dopes not only give a greater tautness, but are in general less affected by humidity than clear dopes. This superiority is also very evident after weathering. Fig. 8 shows the difference in tautness obtained with clear and pigmented dopes before and after weathering.

It was found that the application to fabric of 1 oz. per sq. yd. of cellulose acetate in the form of pigmented dope gave on the whole better tautness results than were obtained with 1.5 ozs. of cellulose acetate covering the same area, when applied as clear dope. Thus by pigmenting a dope, a saving in cellulose acetate is obtained without loss of efficiency. Pigments also lessen the liability of a dope film to crack on weathering.

The pigments mostly favoured for the preparation of pigmented dopes are yellow ochre and black, red oxide of iron and aluminium powder. The tautness at high humidities appears to be retained on weathering to a greater extent with aluminium than with other pigments. The greater the amount of pigment at any rate up to 1½ lbs. per gal. for an 8.5 per cent. cellulose acetate dope, the more efficient is the dope as a tautening medium. Highly-pigmented dopes tend, however, to become brittle on exposure, and it is generally desirable to limit the pigment to about 9 ozs. per gal. if a long life is required.

(b) Varnishing the Dope Film

The application of waterproof varnish to the upper surface of doped fabric retards the rate of moisture absorption by the dope film without influencing to any appreciable extent the absorption by the fabric. Consequently this treatment reduces the rate of loss of tautness of doped fabric when brought from an atmosphere of low humidity to a high one. The effectiveness of varnishing is limited by the fact that, in practice, moisture can still enter the dope through the underside of the fabric. If this side was also protected by varnish, it was found that the variations in tautness with changing humidity were considerably lessened (Fig. 9).

(c) Comparison Acetyl and Nitro-Cellulose Dopes

Nitro-cellulose was, we believe, the first cellulose ester to be used on aeroplane wings. It apparently came into use in this country after starch, gelatine, casein, etc., had been tried, but was soon replaced by cellulose acetate. During the war it was largely used on training machines as a fabric-tautening medium, and in the form of P.C.10 and V.84 as a protective covering on fighting machines. In America nitro-cellulose dopes appear to have been used extensively before the war, and many of the doping schemes examined during and after the war have consisted either of nitro-cellulose alone or in combination with acetyl cellulose; in both cases the dopes acted as tautening media.

With respect to their use on aircraft, the main differences between nitro and acetyl dopes lie in their relative efficiency in maintaining a uniform tautness of fabric under varying humidity conditions and in their relative inflammability.

Nitro-cellulose doped fabric is less sensitive to changes of humidity than fabric treated with any of the cellulose acetate dopes we have so far tested.

From reports which have been received, it would appear that this difference is large enough to be appreciated in practice. On this point it may be of interest to quote two of the reports received from Air Force stations.

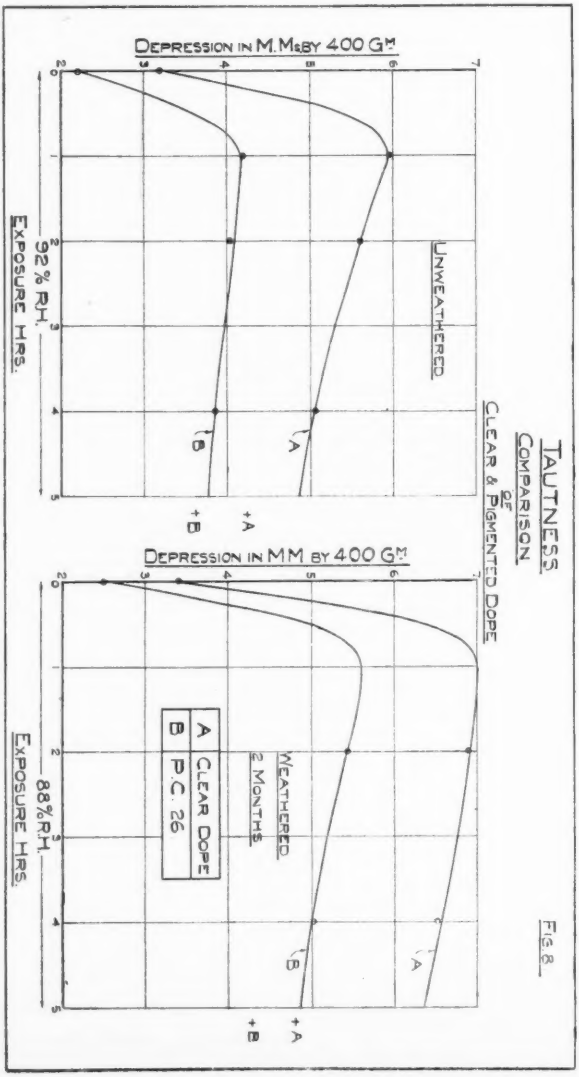
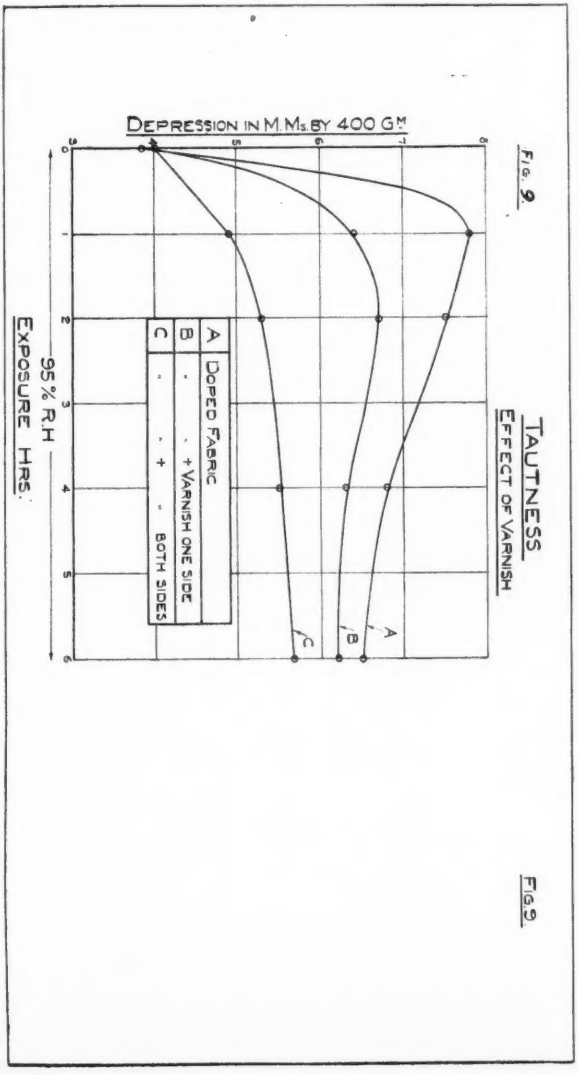


Fig. 8.

A report from Felixstowe received in 1917 accompanied by samples of doped fabric from seaplanes states "The American fabric and dope (sample A) is much superior to others at this station, and remained drum taut since November, 1916, in spite of hard work and sea water." As regards sample B, doped and varnished at Felixstowe, the report states that "the fabric had the same length of service as sample A but became quite soggy in use." Sample A was flax with clear nitro dope, free from fireproofing agents and was unvarnished. Sample B was flax with clear acetyl dope and a varnish layer.



A report from Grain (July, 1920), accompanied by two samples of doped fabric, is to the effect that the machine from which the samples were taken was first flown in August, 1918, had been moored out for considerable periods in bad weather, and the fabric was still drum taut and in excellent condition. The report concludes "(this) system of doping appears to be far superior to any system used on British-built machines." Sample A (upper surface) was flax, with clear nitro dope followed by acetyl dope and a final coating of P.C.10.

Sample B (lower surface) was similar, except that the final covering was V.114.

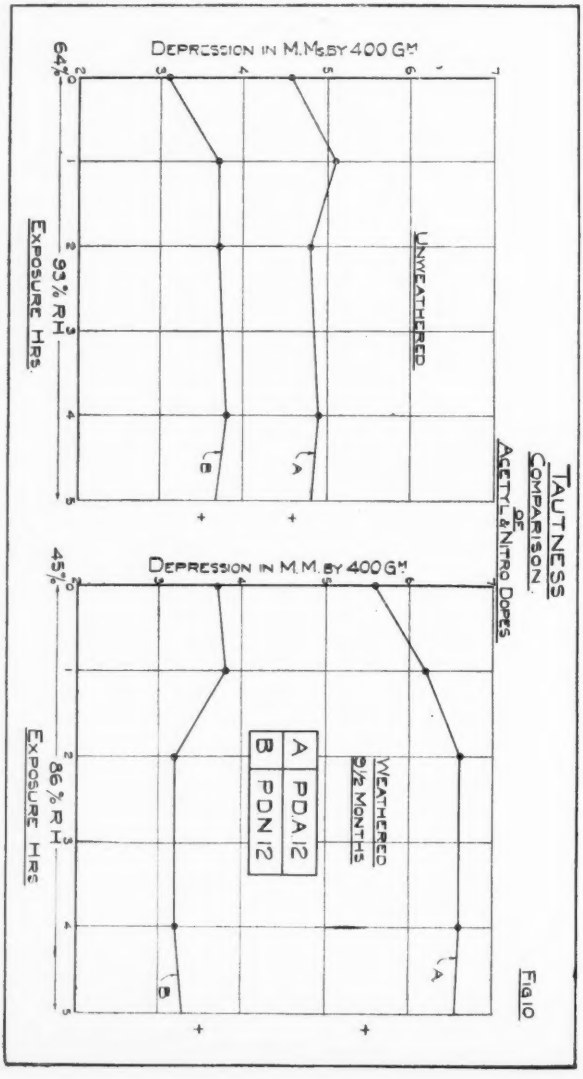


Fig. 10

In both these cases clear nitro-cellulose dope was used.

As with acetyl dopes, the pigmentation of nitro-cellulose dopes results in greater tautening power and reduced sensitiveness to humidity changes.

The relative tautening action of a nitro and acetyl scheme is shown in Fig. 10. Here the change in tautness with humidity of fabric with P.D.N.12 (nitro) and aluminium varnish is compared with P.D.A.12 (acetyl) and aluminium varnish.

Besides giving a more uniform tautness, nitro dopes possess greater tautening power. It was found that the application to fabric of 1.5 ozs. per sq. yd. of nitro dope gave nearly the same degree of tautness as 2 ozs. of acetyl dope. The smaller loss in tautness obtained with nitro dope when the humidity is suddenly increased may be attributed to its low water absorptive capacity as compared with acetyl dope. This is shown in Table IV., which gives the rates of absorption of moisture by dry films of standard nitro and acetyl dope when brought into an atmosphere of 90 to 95 per cent. R.H.

TABLE IV.

Time exposed (hours).	% Increase in weight.	
	Nitro.	Acetyl.
1	2.1	6.6
2	2.5	6.9
4	2.7	7.0
7	3.0	7.1
12	3.0	7.1

(d) Relative Inflammability of Nitro and Acetyl Dopes

Fires on aeroplanes may occur in the air or on crash. Those in the air appear generally to arise from ignition of the petrol either by the engine or through defects in the electrical installation. In investigating the part which doped fabric might play in such fires, experiments were performed with aeroplane wings doped with acetyl and nitro schemes respectively in the slipstream of a propeller (about 40 m.p.h.), the wind blowing across the plane as in flight.

Petrol was poured on the upper surface of the wing and ignited. The flames were blown out without much damage being done to the wings.

The experiment was repeated, the petrol being allowed to burn for some time in still air so that the fabric got well alight before it was subjected to the slipstream. The flames were again quickly extinguished.

A considerable quantity of petrol was then poured into the wing through holes in the top and ignited. The flames were soon extinguished by the slipstream after those parts of the fabric which were shielded from draught had burnt away.

As regards fire risks in the air, there appears to be little difference between the doping schemes.

In crashes, fires have occurred with aeroplanes constructed all of metal and also with those treated with fireproof dope, thus indicating that the danger of fires after a crash cannot be eliminated by using fireproof materials. On some machines, however, there is a possibility of doped fabric becoming ignited in a crash by contact with hot parts of the engine. In this connection the influence of nitro and acetyl dopes respectively on the ignition temperature of fabric is of importance.

Various methods of determining the ignition temperature have been tried.

A simple method of determining ignition temperatures is to drop pieces of doped fabric of definite size on to an iron plate floating on a bath of solder and to note the lowest temperature at which incipient glowing occurs. Once the fabric

begins to glow, there is always a danger that it may burst into flames when assisted by a slight breeze. Using this method, the following ignition temperatures were obtained :—

Linen	430°C.
(Nitro) P.D.N.12+V.84	435°C.
(Acetyl) P.D.A.12+V.84	430°C.

Both doped fabrics ignited at practically the same temperature as the fabric.

In a crash, a very rapid cooling of some of the hot parts, such as thin exhaust pipes, will take place when the engine stops. This condition is to some extent reproduced by placing the doped fabric on an iron plate heated by a burner, the gas being extinguished at the same moment. With iron plates 5ins. square and 28 and 16 gauge respectively, and measuring the temperatures by a thermo couple welded to the plates, the following ignition temperatures were obtained :—

	28 gauge.	16 gauge.
(Nitro) P.D.N.12+V.84 ...	505°C.	485°C.
(Acetyl) P.D.A.12+V.84 ...	505°C.	505°C.

With the 16 gauge plate the nitro scheme gave a lower temperature.

Further, in a crash it may happen that the doped fabric may fall on a hot part in such a crumpled condition that confined air spaces are formed in which combustion may be initiated more easily. An attempt was made to reproduce this condition.

The apparatus consists essentially of a cylindrical iron cup, 2ins. diameter, designed to have a particular cooling rate based on the rate of cooling of an S.E.5 manifold. The shape of the vessel ensured a limited circulation and admixture with air. By altering the height, the volume of air could be varied, and by using different openings the effect of retarding access of fresh air could be determined.

Alteration in diameter of the vessel was considered to be equivalent to altering the size of test piece. A thermo couple was welded to the bottom of the vessel.

The method of carrying out the tests was to heat the cup up to a temperature about 20° higher than that proposed for trial, then to turn off the burner, and when the indicator recorded the selected temperature, a disc of doped fabric was dropped in. This procedure was repeated at various temperatures. Cups ½in. to 3ins. in height with openings ½in. to 2ins. were used.

With small openings the nitro dopes usually gave higher values, *e.g.*, nitro 507°C., acetyl 456°C.; in other cases the ignition temperature of the nitro was some 20°C. lower than the acetyl, *e.g.*, nitro 423°C., acetyl 446°C.

The " Enclosed " method described in B.E.S.A. D.101 goes a step further in that an attempt is made to minimise the loss of heat and to obtain conditions which, though not strictly adiabatic, approach thereto. This method gives lower values than any of the other methods.

Linen	335°C.
(Nitro) P.D.N.12+V.84	325°C.
(Acetyl) P.D.A.12+V.84	325°C.

It may be concluded that there is very little difference in the ease of ignition of these typical schemes.

The results were not very different when the V.84 was omitted from the scheme.

	Solder Bath.	" Enclosed."
Pigmented nitro	430°C.	305°C.
Pigmented acetyl	415°C.	325°C.

The ignition temperature of the fabric itself is evidently a controlling factor in determining the upper temperature limit for the various types of acetyl and nitro doping schemes.

When once a fire has been started in a crash, the great danger, of course, is that the petrol may become ignited; compared with this danger, that due to the difference in rate of flame propagation of the nitro and acetyl scheme (approximately 2 : 1) is probably of little significance.

(e) Application of Dope to Fabric

(1) *Thickness of Film.* The tautness of fabric increases with each successive coat of dope, but the gain in efficiency becomes less with each successive coat.

With standard acteyl dope on a closely-woven fabric, there is little advantage in adding more than 2 ozs. per sq. yd. to the fabric and this is sufficient to provide a good finish.

Fig. 11 shows the tautness obtained with different weights of standard acetyl dope on linen fabric, the measurements being made at normal humidity.*

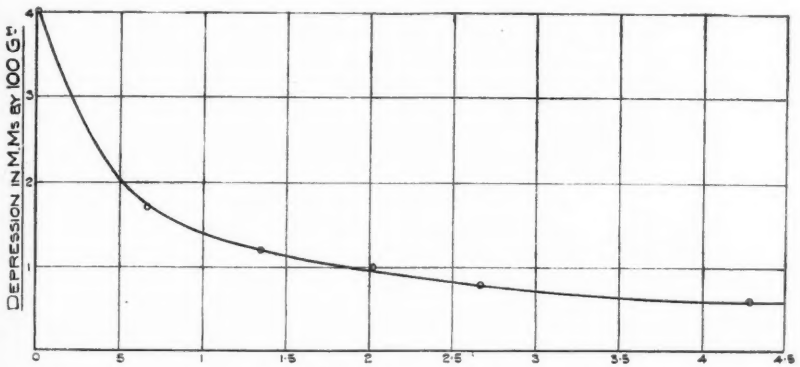


FIG. 11.

It should be noted, however, that fabric with a thin dope covering (1 oz. per sq. yd.) loses its tautness in a moist atmosphere at a quicker rate than that with a standard covering of 2 ozs. It also attains a greater degree of slackness but makes a quicker recovery on bringing into a dry atmosphere (Fig. 12).

(2) *Distribution of Dope.* In covering aeroplane parts, the dope is applied to one surface only of the fabric. A greater tautness is thus obtained with a given quantity of dope than if the dope is distributed on both sides, as has been suggested for airship covers.

The loss in tautness on weathering, however, appears to be slightly less with fabric doped on both sides; the complete surrounding of the threads with dope possibly reduces the normal stretch of the fabric which occurs with age. Tautness-humidity curves of fabric doped one side and both sides before and after weathering are shown in Fig. 13.

For airship covers, it has been found convenient to partially dope the fabric before fixing it to the structure.

Experiments carried out in this connection indicate that good results can be obtained if the dope is applied to the fabric while it is under considerable tension,

* If reciprocals of depression are plotted a straight line relation is obtained.

the dope being allowed to become thoroughly dry before the tension is taken off. The fabric was dipped in dilute dope and allowed to dry :—

A. Without tension.
B. Under a tension of 0.15 lbs. per in.
C. Under a tension of 5 lbs. per in.

After fixing to frames the doping was completed in the usual way and the tautness compared with that of a standard frame D. The tautness at low humidity and after exposure for various periods to a nearly-saturated atmosphere is shown in Fig. 14.

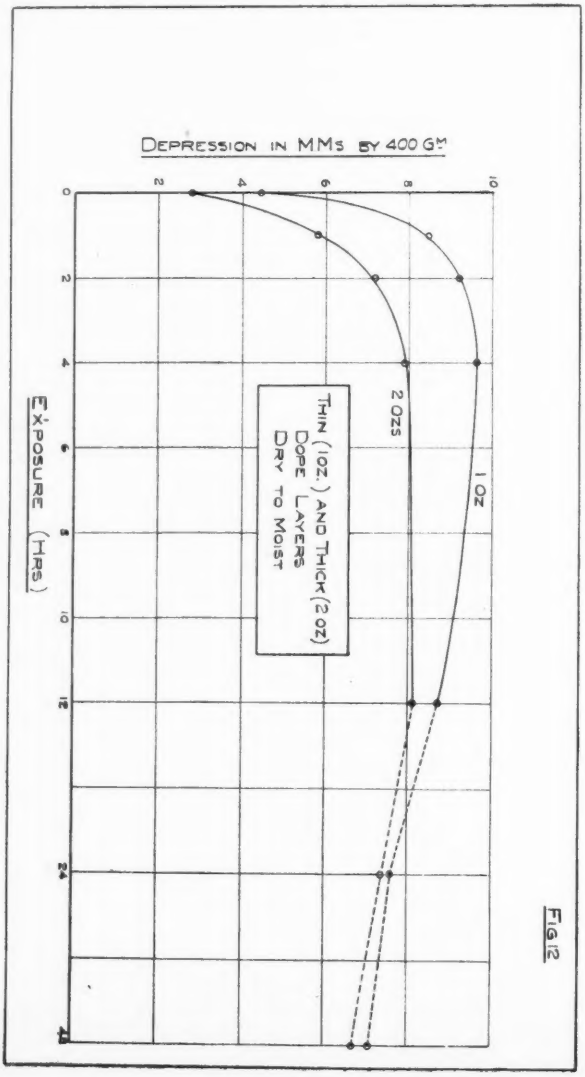
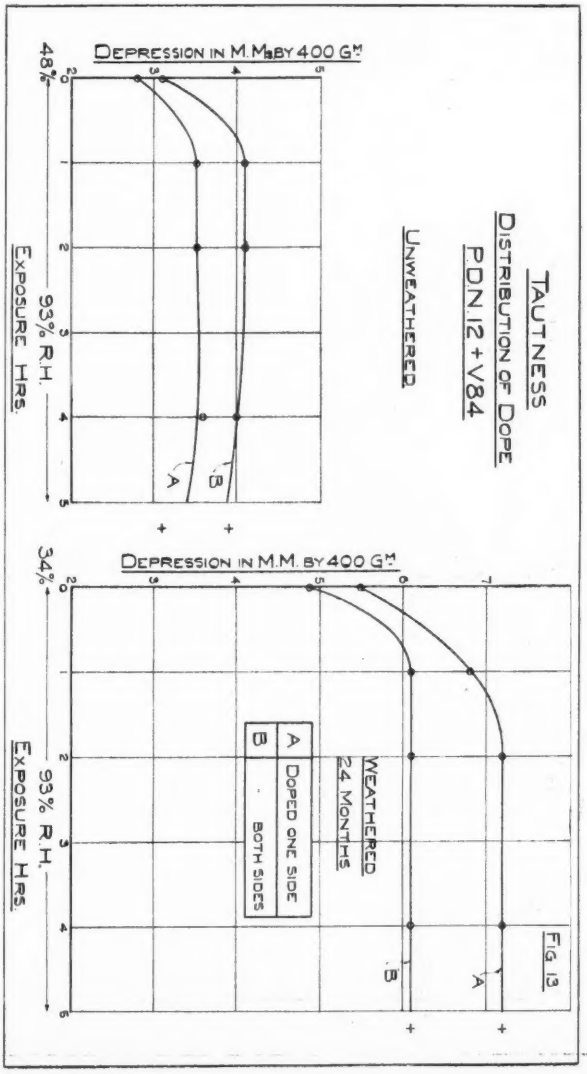


FIG 12

The results were unsatisfactory when the fabric was allowed to contract freely during the initial treatment. The more stretch taken out of the fabric before attaching it to the framework, the better the tautness. There is still a falling off in the tautness at high humidities on weathering, and no method of overcoming this defect has yet been found. A method of dope application which has been tried in connection with airship covers is to fully dope the fabric while under tension. When thoroughly dry the cover is loosely attached to the framework and the dope softened by the application of a solvent of low volatility. The cover is then pulled as tightly as possible by hand and fixed. Good results have been obtained with large experimental panels weathered for a year at Farnborough.



This method of tautening was adopted on experimental cover sections on R.34 during the application of the last coat of dope; these sections were tauter than those put on in the normal way.

For work on tautness it is essential to have means of controlling the humidity of the surrounding atmosphere for long periods. In the constant humidity chamber at the R.A.E. (see Photo C) the temperature can be maintained within 0.1° between 15° and 35° and the humidity within 1 per cent. between 30 and 95 R.H.

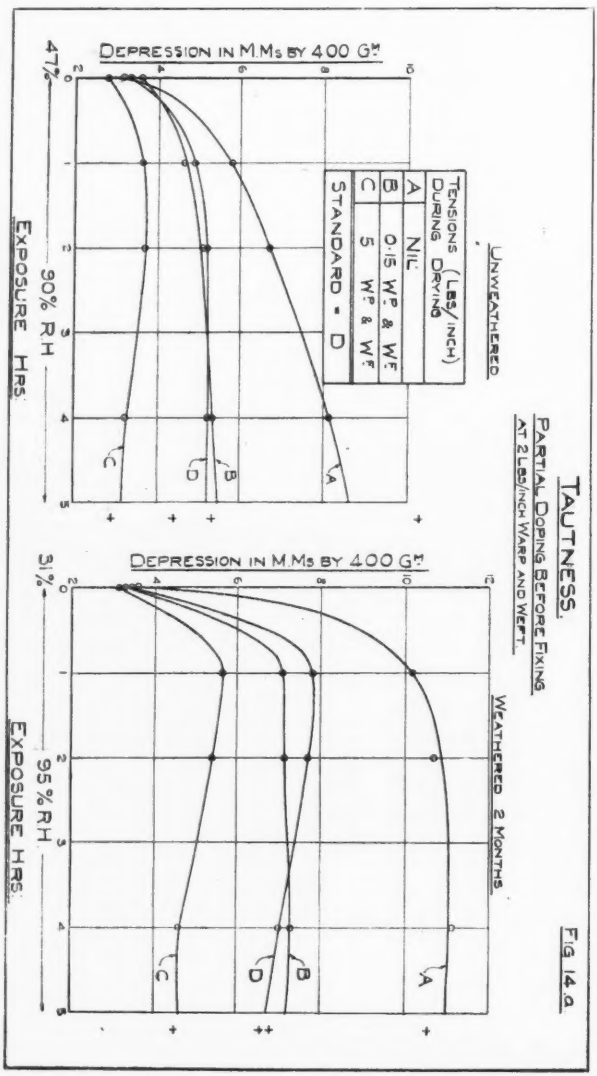


FIG. 14.a.

2 Strength

While the dope component may be regarded as the predominating factor in determining tautness, a wing covering relies on the fabric for its strength.

The application of dope increases somewhat the tensile strength of aero fabric, but it reduces the tearing strength.

For wing coverings, resistance to tearing is of greater significance than the simple breaking strength.

Cotton fabric, even when made from mercerised yarns, is inferior to linen in tearing strength; while silk, although superior to cotton in this respect, is less satisfactory from the tautness standpoint.

On these grounds, linen is generally preferred in this country for wing coverings.

The standard specified by B.E.S.A. is a 4 oz. fabric with approximately 80 threads per in. warp and 90 weft.

A 12in. circular area of the doped fabric has a bursting pressure of 12 lbs. per sq. in. unwounded, and with 1in. × 2in. wound cuts in the weft this falls to 4 lbs. and 3 lbs. respectively. When heavily calendered a surface is obtained which requires little dope for tautening, and which can be fairly easily protected from actinic light.

If greater tearing strength is required, Turner and Barr have suggested the use of coarser fabric of the same weight.

Little success has been obtained by the use of weaves other than plain, owing to the binding action of the dope and the importance of a good doping surface.

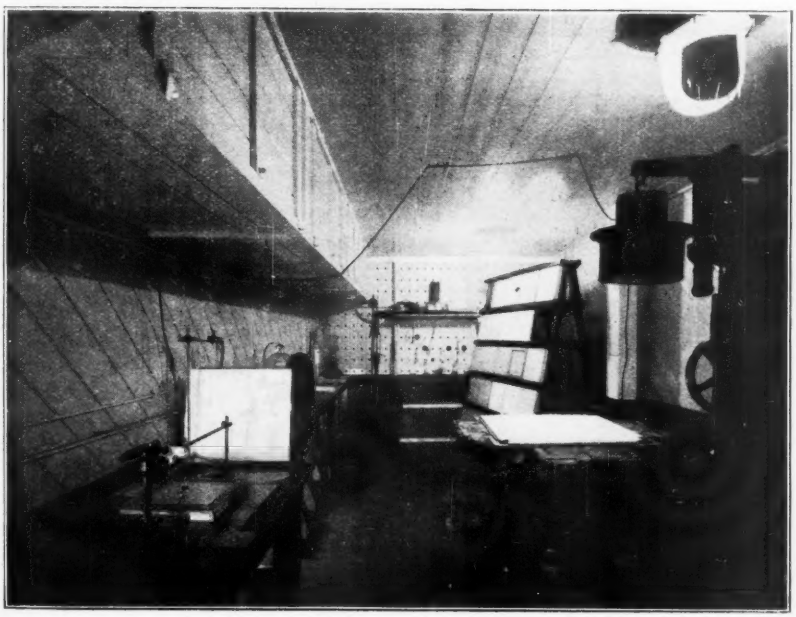


Fig. C.—*Constant humidity chamber at the R.A.E.*

Fabrics suitable for aero coverings all weather badly; cotton and linen (4 ozs. per sq. yd.) may lose 45 per cent. of their strength after one month's weathering in this country, while silk may lose as much as 75 per cent.

When protected from light by an opaque layer, there is practically no difference in their rate of deterioration.

A—Deterioration in Strength

Standard dope has little influence on the rate of deterioration in strength of fabric exposed to atmospheric conditions. In this country, except possibly in neighbourhoods where the atmospheric acidity is high, the loss of strength on exposure during the winter months appears to be negligible, but may become serious after one month's exposure in summer, or after a shorter exposure in sunnier climates.

Some idea of the relative destructive action of the weather at different times of the year may be gathered from the following Table V. This shows the percentage loss in strength of linen doped with standard acetyl dope after exposure at Farnborough for periods of one month from July, 1922, to August, 1923.

TABLE V.

1922.	Per cent. loss in strength.	1923.	Per cent. loss in strength.
July	31	January	5
August	25	February	6
September	20	March	24
October	19	April	19
November	Nil.	May	30
December	1	June	35
		July	45
		August	38

Little deterioration in strength was observed with the specimens exposed in November, December, January and February respectively, while July was the most destructive month of last year, the loss in strength amounting to 45 per cent.

Although the deterioration of fabric on exposure to weather is known to be mainly due to the action of sunlight, the exact distribution of destructive power in the sun's spectrum has not yet been determined. As the experiments by Aston, in which the sun's spectrum was thrown on to a series of threads, failed to yield decisive results, the most obvious method of dealing with the problem is to expose fabric or threads to sunlight under screens which are transparent to a small range of wave length only. The chief difficulty lies in obtaining suitable screens which are permanent to light.

Screens covering a small range of wave length can be obtained by the use of dyes, but they are affected by light. Experiments have been made using coloured glass plates, the absorption spectra of which were determined.

Frames covered with linen fabric and treated with standard dope were prepared.

The glass plates were fixed to the upper surface of the doped fabric, the junction between the doped fabric and the glass being made watertight.

A frame of doped fabric without glass was used for comparison.

The frames were exposed from April, 1919, until November, 1921.

The tensile strengths after exposure, and the mean rates of deterioration calculated on the assumption that the decrease in strength is logarithmic, are given in Table VI.

TABLE VI.

Glass.	Strength lbs./in.	Rate of* deterioration.	Wave lengths transmitted AU.	Observed intensity of effect of light on plate.
Red	102	4	6250-5550	—
Orange red ...	98	5	6300-4900	—
Green	89	7	5600-4650	—
Orange ...	56	19	6300-3320	Weak from 4600-3800.
Blue green ...	47	23	5500-3500	
Yellow	14	52	6300-3150	Denser than orange 4600-3150. Weaker than blue green 4600-3800.
Purple	12	56	6100-5000 4300-3320	Denser than yellow or blue green 4000-3320.
Violet	8	66	6300-3230	Very dense 6300-3270.
Clear	6	73	6400-3100	Very dense.
Blue	4	83	6400-3140	Very weak 6400-5400. Weak 5400-4600. Equal to density to clear 4600-3140.
Dope film ...	—	—	6500-2260	—
No glass ...	2	100	6600-2160	—

Strength of doped fabric unweathered, 120 lbs./in.

The absorption spectra of the glass plates and of a film of standard acetyl dope were determined, using a quartz prism spectograph with the iron arc as the source of light (Photo D).

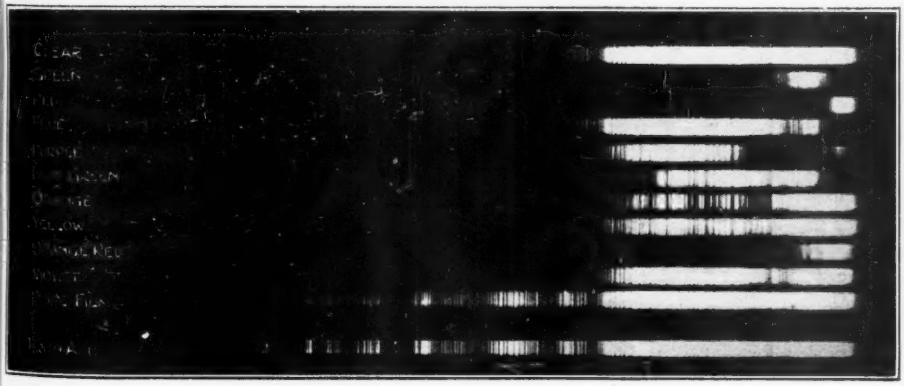


FIG. D.—*Absorption spectra.*

* Log. (initial strength/final strength).

In those cases in which the fabric has lost over 90 per cent. of its strength, *i.e.*, violet, clear, blue and no glass, too much reliance must not be placed on the comparative rates of deterioration, as it was difficult to carry out the tensile tests.

From the other results, however, definite conclusions may be drawn.

Red, orange red and green give excellent protection, and the slight increase of deterioration from red to green corresponds to a slight extension of the transmitted spectra towards the blue.

It is obvious, therefore, that the rays from the red up to $\lambda = 4650$ AU show only a relatively slight destructive action.

The light transmitted through the purple glass lies between 6100 and 5000 AU and between 4300-3320 AU. Its destructive action is confined almost altogether to the range 4300-3320. It may be concluded therefore that the most destructive rays have a wave length less than 4300.

Blue green transmits more light than yellow from 4600 to 3840, but less from 3840 to 3150, and its protective power is considerably greater than that of yellow; it therefore appears that the range 3840-3150 is considerably more destructive than 4600-3840.

The range 3840 to 3150 is dense in the spectra of glasses with slight protective power, and the most destructive spectra shows a slight extension towards the ultra-violet. Further tests have shown that clear glass which absorbs rays of wave length less than 3100 AU has practically no protective action.

The conclusion seems justifiable that the most harmful part of the sun's spectrum lies between the wave lengths 3900 and 3100 AU.

As it has been shown that clear glass reduces the destructive effect of the mercury arc almost to zero, the region of maximum destructive effect is therefore different in the two spectra.

In view of a suggestion that had been made that the rate of deterioration of fabric was a simple function of the total amount of radiant energy absorbed, tests were carried out with Wilson radio integrators. Two of the instruments—one filled with alcohol and the other with a low boiling petrol fraction—were exposed to a filament lamp with quartz bulb. The coloured glass plates were interposed between the lamp and the radio integrators, and the relative amount of energy transmitted by the glasses was compared. The tests were carried out in still air, as the radio integrators were known to be sensitive to wind.

The results show no definite relation between the energy transmitted and protective power. This, of course, was to be expected, as the destructive action of light has been shown to depend primarily on wave length. Moreover, the two instruments placed the plates in a different order.

B—Factors Affecting Deterioration

The effect of the atmosphere surrounding the fabric threads, on the deterioration by sunlight, has been determined by exposing washed linen threads (Campbell's No. 70 washed by 1 per cent. caustic soda and 1 per cent. soft soap) in sealed tubes. The threads were wound round a plate of glass or aluminium so as to give 40 test pieces.

After exposure from June to December, 1922 (800 hours recorded sunshine) the loss in strength was determined. Details of the treatment and loss in strength are given in Table VII.

TABLE VII.

EXPOSURE OF THREADS IN SEALED TUBES.

Atmosphere.	% loss in strength. R.H. = 65 per cent. T = 21°
Carbon dioxide (dry P_2O_5)	0
Carbon dioxide moist	0
Vacuum .06 m.m.	4
*Vacuum .015 m.m.	4
Vacuum .06 (P_2O_5)	0
Hydrogen (dry P_2O_5)	0
Hydrogen moist	0
Water vapour	0
Oxygen (dry P_2O_5)	37
Oxygen moist NaOH solution in tube	78
†Ozone and oxygen	76
Air (dry P_2O_5)	8
Air R.H. 50 to 80 per cent.	29
Air moist	33
Air and acetic acid 50 per cent. aqueous solution in tube	50
Water saturated with oxygen	9

Considerable deterioration occurred with

1. Moist air.
2. Dry and moist oxygen.
3. Air and acetic acid;

but under the other conditions deterioration was negligible.

The conclusion from these tests—neglecting the action of acetic acid—is that oxygen is necessary for deterioration of fabric by sunshine, and that the action is accelerated by the presence of water vapour. To obtain more information on the influence of moisture, the test with oxygen and P_2O_5 is being repeated with threads dried at 110°C.

Another set of tests was carried out to see whether there was any difference between a glass, quartz and dope film enclosure, and also to see whether dope has any influence on the deterioration. Threads in open tubes were exposed from June to December, 1922 (800 hours recorded sunshine).

TABLE VIII.

EXPOSURE OF THREADS IN OPEN TUBES.

	% loss in strength.
Linen in glass	48
Linen in quartz	50
Acetyl doped linen in glass	73
Linen in tube of doped film	55

There was practically no difference in deterioration with glass and quartz tubes. The loss was a little greater with the dope film tube.

Doping the threads caused an increased deterioration. This is of interest, since in exposures on fabric in the open, a dope layer usually affords a little pro-

* The pressure in this tube rose to 7.0 m.m. after 670 hours recorded sunshine; the test was then stopped.

† This tube was fitted with platinum electrodes, which were sparked occasionally to produce ozone.

tection to the fabric. It has been shown, however, that part of the deterioration of undoped fabric on exposure is sometimes due to the impurities present in rain water.

The test in the sealed tube indicated that acetic acid, which is formed by hydrolysis of acetyl cellulose, may cause deterioration in presence of sunlight.

By fixing a gauge to tubes with threads in an atmosphere of moist oxygen, it was found that a progressive diminution in pressure occurred on exposure to sunlight, *e.g.*, in one case an exposure from August to October, 1923, gave the following values :—

Hours recorded sunshine.	Pressure m.m.
0	767
77	760
146	754
288	747

It is hoped that it may be possible to correlate the rate of oxygen absorption with the loss in strength, thus providing a more delicate means of following deterioration than that used at present.

C—Protection of Fabric from the Deteriorating Action of Light

Protection of fabric from the deteriorating action of light can be obtained by covering the dope layer with an opaque varnish or by introducing pigments into the dope.

The first method was used early in the war, when the nitro-cellulose varnish P.C.10 was devised.

Pigmented oil varnishes have also been largely used for this purpose.

The present Air Ministry scheme of protection is to pigment the dope. This method appears to have several advantages over the varnish method.

1. The introduction of pigments into dope results in an increased tautness of the fabric and also reduces the slackening which invariably occurs in a moist atmosphere.

2. A saving in weight and greater simplicity in application, since only one medium is involved.

3. It is easier to obtain a covering of uniform opacity, since a larger number of coats of dope are used.

The number of pigments which have been found to give satisfactory results is not large. Of these, the best we have tested are red oxide of iron and the mixture yellow ochre and carbon black (khaki). The red oxide has the greater covering power and opacity to destructive light.

These pigments can be readily obtained in a finely divided condition and only settle very slowly in a dope medium. They have apparently no adverse influence on the viscosity of the dope, a fault found in a number of pigments.

The amount of pigment which can safely be added to a dope depends mainly on the cellulose ester content and on the proportion and nature of the non-volatile softener. Over-pigmentation leads to early cracking of the dope film on weathering.

For a 7.5 per cent. cellulose acetate solution containing $2\frac{1}{2}$ per cent. of triphenyl phosphate it has been found advisable not to add much more than 8 ozs. of pigment per gallon of dope.

Experiments have been made to determine the amounts of various pigments necessary to give an opaque covering.

It is concluded that ½oz. per sq. yd. of good quality ochre and black and less of red oxide, if properly distributed, will ensure good protection of fabric during the present-day life of aeroplanes.

Both nitro-cellulose and acetyl cellulose dopes give good results on pigmentation. The pigmented dopes differ but little in protective and lasting qualities, although clear nitro is much inferior to acetyl in this respect. Although not so permanent as pigments, a few dyes have given almost equally good protection against the destructive action of light.

On tautness grounds, however, they cannot replace pigments, but if added to a pigmented dope they serve to protect those parts of the fabric which may be insufficiently covered due to faulty distribution of the pigment.

A considerable improvement is effected by using an aluminium varnish over pigmented dope. Aluminium powder has a low extinction coefficient for actinic light and hence is unsuitable as a light excluder, but next to white pigments, which have obvious disadvantages, aluminium powder appears to give the best light-reflecting surface for wing coverings.

The temperature in the inside of wings with a khaki finish may be in summer sunshine of the order of 10°C. higher than when aluminium is used as a finishing varnish (Fig. 16).

As previously stated, an aluminium covering also effects an improvement in tautness.

The results of weathering tests extending over two years of a number of doping schemes are given in the following table :—

TABLE IX.

Exposure period, June, 1921, to August, 1923. Place, Farnborough.

	Weight,* oz. per sq. yd.	Per cent. loss in strength.
Dyed and red pigmented nitro dope + V.84 ...	6.2	3
Red pigmented nitro dope + V.84	6.3	11
Standard acetyl dope + P.C.12 + V.84	6.1	17
Khaki acetyl dope	5.8	24
Standard acetyl dope + P.C.10	6.6	27
Standard acetyl dope	6.7	93

V.84, P.C.10, P.C.12 are nitro-cellulose varnishes containing aluminium khaki pigment and red oxide of iron respectively.

There is generally some deterioration even when a comparatively heavy weight of protective covering has been applied to the fabric. This may be due in part to bad distribution of the pigment, leaving some threads insufficiently protected.

With rough and uneven fabric this is most likely to occur. In a few cases, notably with closely-woven fabrics having a smooth surface such as the standard mercerised cotton, no loss in strength was detected after a year's weathering.

From the tests on threads it seems safe to assume that the dope itself may be partly responsible for the deterioration. It is known that some types of cellulose acetate and nitrate are relatively unstable and contain impurities likely to attack cellulose.

* Includes fabric.

There is also some evidence that heat may play a part in the deterioration, especially in hot climates.

As is to be expected, the deterioration of doped fabric proceeds at a more rapid rate in hot and sunny climates than in this country.

To convey some idea of the relative rates of deterioration in Egypt and Farnborough, a few comparative results are given.

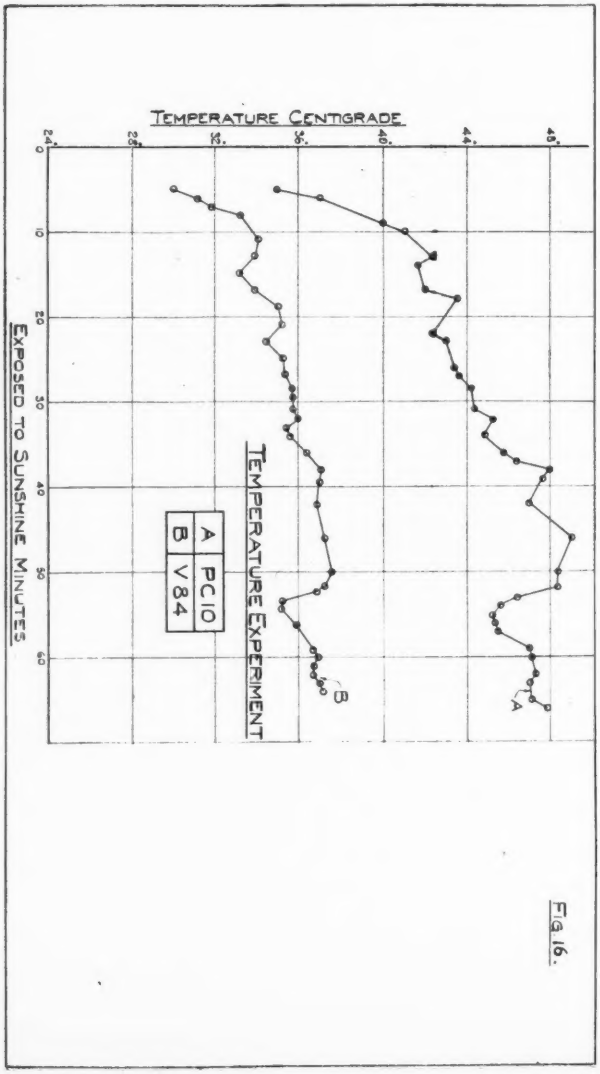


Fig. 16.

TABLE X.

Fabric.	Dope.	Weathering period.	Place.	Per cent. loss in strength.
Mercerised cotton.	Pigmented nitro	15 months.	Egypt.	21
	+ V.84.	19 months.	Farnboro'.	12
Linen.	Pigmented acetyl	$5\frac{1}{2}$ months.	Egypt.	21
	+ V.84.	12 months.	Farnboro'.	12
Linen.	Clear acetyl.	$5\frac{1}{2}$ months.	Egypt.	75
		12 months.	Farnboro'.	84

It should be mentioned that humidity has a different effect on the breaking strength of unweathered and weathered doped fabric. The value obtained for loss in strength is therefore greater when the comparison is made at a high humidity than at a low one, *e.g.*, a doped linen fabric weathered for four years gave the following values :—

	Breaking strength lbs. per in.		
% humidity	40	95	Wet.
Unweathered	87	125	125
Weathered	33	28	25
% loss in strength	62	78	80

The usual method of testing the protective qualities of a doping scheme is to carry out prolonged weathering tests.

From the knowledge obtained of the rates of deterioration of fabric under different coloured glasses, it was thought possible that transparency to actinic light measured by photographic methods might be found parallel to transparency to destructive wave length.

The relative transparencies to actinic light of the various plates were measured, using different types of sensitive paper and different sources of light.

It was found that the order of opacity of the plates to actinic light showed a close parallelism to the order of protective power, particularly in the less transparent. Printing out paper gives very satisfactory results, the best illuminant to use being daylight. One great advantage of P.O.P. over bromide (suggested by Barr) is the ease of manipulation, as it is possible to inspect it during exposure and compare directly the density of the images. It might be possible to establish a standard of protective power such as that of an orange red glass absorbing all light beyond wave length 4900 AU. A dope or varnish film could be compared in a few minutes with the standard glass.

Although considerable progress has been made towards the solution of the problem of a satisfactory covering for aircraft, much remains to be done, especially with respect to airship covers, where, owing to the enormous cost of recovering, success depends largely on the provision of a light cover which will retain its properties for periods compared with which the life of the cover of an aeroplane is comparatively short.

Discussion

Mr. A. J. A. Wallace Barr, who opened the discussion, said he considered the statement regarding the lower sensitiveness of the nitro dope as compared with acetate dope was rather sweeping, having regard to the fact that the lecturer had only compared, presumably, from his figures, one acetate dope, which had never been actually a Government standard, with a nitro dope which one admitted

was a very good nitro dope of its class. It seemed hardly fair to condemn acetate dope unless it was tested fully. If the difference between the two was so marked, it was a pity that this lecture was not given seven or eight years ago, when this question was very acute, because it would have saved the country, and numerous individuals, vast sums of money in connection with acetate production. With regard to the test referred to in the report from Felixstowe, on the transparent nitro, the people at Felixstowe had reported that the transparent nitro gave very good results on weathering. Later on, however, the author had said that the transparent nitro was markedly inferior to transparent acetate. With regard to the question of inflammability, he was of opinion that the lecturer had passed over the question of the rate of burning rather too rapidly. After all, if the difference in the rate of burning was in the neighbourhood of .2 : 1, it would mean two minutes to one minute, and that difference of one minute might give passengers sufficient time to get out of a machine, which, after all, was a matter of some importance. As to Table XI., the lecturer had given dyed and red pigmented nitro dope + V.84, but had not given A.D.P. + V.84. Was there any particular reason for that? Again, with regard to the table relating to the weathering of doped fabrics in Egypt and at Farnborough, it was difficult to compare the results, because two different fabrics were mentioned.

Mr. F. CUMBERS congratulated Dr. Ramsbottom on his very able lecture and thanked him for the care he had given to the subject, but thought it was more or less wasted because the parallels which had been given were not true. He had taken an admittedly worn out and obsolete cellulose acetate dope and had compared it with the most up-to-date nitro cellulose dope he could find, and then condemned the cellulose acetate. Anybody who knew anything about the latter would admit that it was not the most up-to-date material, and it seemed a pity that when research was carried out and comparative tests were made, the most up-to-date materials were not obtained. Therefore Mr. Cumbers maintained that the figures in the paper were not reliable and were practically out-of-date. He would like to know whether Dr. Ramsbottom had tested later products, both plasticisers and cellulose acetate.

[I would like to add that my remarks on out-of-date material referred to "A.M.A." dope and the report from Felixstowe, 1917, which should not have been used to-day as an argument to prove the inferiority of cellulose acetate. The Government war material has been superseded by a greatly improved post-war product. Also there are modern plasticisers which are constant and non-hygroscopic. Therefore if post-war materials were used as a standard of comparison, I claim that the many advantages of cellulose acetate dope over nitro would be demonstrated.]

Mr. J. FLETCHER also congratulated Dr. Ramsbottom. He believed there was a very simple confirmation of Dr. Ramsbottom's contention as to the relative effect of humidity on cellulose acetate and cellulose nitrate; that was to be found in the cinema industry. If it were possible to use cellulose acetate in the cinema industry it would be of great advantage, chiefly from the inflammability point of view. But it had been found that if cinema films made from acetate were used in humid atmospheres they stretched, and as humidity increased the perforation at the edges of the films would not fit into the machines. Also he believed that after passing through the camera for some time the film became very brittle. He would have liked to have heard some theoretical reason why a film lengthened when exposed to humid air. He asked whether the solubility of cellulose nitrate and cellulose acetate and the difference in their molecular complexity had anything to do with the difference in water absorption.

Mr. D. R. DAVEY said he was reluctant to speak in the presence of many who were obviously experts on this matter of dope and the preparation of dopes, but there were one or two points he would like to raise. Considerable reference

had been made to the effect of humidity upon tautness, and he was wondering if we were right in pressing the point, or if we were unduly exaggerating things. We might remind ourselves of this fact, that the fabric, of itself and by itself, tautened considerably as the amount of moisture in the atmosphere increased, and it would appear that a good many of these changes, which were the result of humidity, were brought about not simply by the film of dope, whether nitrate or acetate, but in part, and perhaps in a very large measure, as the result of the effect of moisture on the fibres of the cellulose itself. He believed it was recorded by both German and English chemists that the fibres of cellulose, when moistened, would increase in size, so far as diameter was concerned, 25 to 30 per cent., but in length only a fractional part, less than one per cent., and he supposed that tautening was largely due to the swelling of the fibres as the result of absorption of moisture, thus filling up the air spaces that did exist in and between the fibres, and so giving a continuity of surface which did not exist before. Further, we might usefully make a note of the fact, with regard to these moisture absorption figures, that although the acetate admittedly absorbed a greater amount of moisture that the nitro cellulose, yet neither the acetate not the nitrate absorbed so much moisture from the atmosphere as the fabric itself. For instance, we had a normal hygroscopic moisture with cotton or linen of from 6 to 7 per cent., under ordinary conditions of atmosphere, not particularly wet. Under those same conditions the hygroscopic moisture of cellulose acetate would be between 4 and 5 per cent., and the hygroscopic moisture of nitro cellulose would be lower than that, varying probably according to its nitrogen content. But seeing that the moisture in either of these esters was considerably lower than that in the fabric itself, it seemed to him that the variations were not so important as at first appeared. Referring to some of the tables in the paper, Mr. Davey said he had noticed that the presence of small quantities of acetate acid, which it was said could be split off by hydrolysis from cellulose acetate, appeared to cause a tendering action on the cellulose. According to the figures this would appear to be true, but from his experience he was inclined to believe that the tendering was probably caused by traces of sulphuric acid from an impure acetate, the presence of which would also account for the free acetate acid. He suggested that such tests with the high quality cellulose acetates at present on the market would not give similar results.

If the comparison was to be made as between acetate and nitro dopes, one would have to consider the decomposition products of the nitrate in comparison with the decomposition products of the acetate, and whereas in the case of acetate we had organic products, having little or no effect on the cellulose, in the other case we had possibly nitroso and nitric bodies which had a very great effect on cellulose, both hydrolytic and oxidising. One would have liked to have seen comparative tests in that direction between the acetate and the nitrate. The same remarks, of course, applied to the effect of light and sunshine, and perhaps we ought to ask ourselves whether the effect was quite so simple as it at first appeared. He believed most fabrics used in the East were unbleached linen fabrics. These contained traces of nitrogenous bodies, pectic matters, ligno cellulose, waxy bodies, etc., all of which were very much less resistant to atmospheric conditions than cellulose itself. Some of these impurities in unbleached yarns might cause far more damage, especially in the presence of the decomposition products of nitro cellulose, than the films, as such, could possibly cause. Referring to the table on the last page of the paper, in which, he said, some sort of comparison was made as to the effect of weather in Egypt and at Farnborough on acetate and nitro dopes, he pointed out that the nitro dope test was made on mercerised cotton. He had understood the Lecturer to say that mercerised cotton had stood the test of weathering to a remarkable extent, as compared with linen. The mercerised cotton, on which the nitro test was made, was peculiarly stable, or peculiarly resistant to weathering effects, whilst the acetyl test was made on

linen, which the Lecturer had suggested was not so stable on weathering. If we were to get a true idea of the state of things as they existed, it was obvious that we must make tests which were comparable. Continuing, Mr. Davey said he understood the Lecturer to say that clear nitro dope was pretty hopeless, but if it were pigmented, it could be made equal to pigmented acetate. He felt sure the Author would admit that that pigmented dope was not stable in itself, and that its quality could not be maintained. A little while ago he had seen a tender out for the reconditioning of a nitro dope which had become useless, and obviously degradation of a marked order had taken place. It was common knowledge that nitro cellulose dopes did become very much degraded, losing viscosity to such an extent that they had to be reconditioned.

Colonel the MASTER OF SEMPILL said that everyone would admit that no one present had studied the very important question of dopes and fabric more than the Lecturer and that the Society was much to be congratulated on having a paper so full of useful information. He had been struck by two points in particular; the first was the advantages of nitro dope, which had not been fully realised in the past; the second, the " fire hazard " in relation to dope of which so much had been heard. Dr. Ramsbottom showed very clearly that the " fire hazard " had been grossly exaggerated in so far as it related to the use of nitro cellulose dope. Since 1921 he had been concerned with the Imperial Japanese Naval Air Service and orders had been placed for some hundreds of aircraft, the majority of which were still in service. Before specifying the doping scheme careful consideration had been given to the conditions prevailing in Japan and it was clear that the atmosphere during the summer months would always be very humid, and for this and other reasons it had been decided to utilise a nitro doping scheme, viz., P.D.N.12 V.84. A very large number of machines had been treated in this manner, three coats of dope being applied with a brush and one coat of V.84 being sprayed on. A number of machines were treated with sundry other doping schemes, some to approved B.E.S.A. specifications and some being the schemes of the dope manufacturers. This enabled very valuable comparisons to be made and it had been very clearly shown in every case that the P.D.N.12 scheme had advantages over the various other acetate schemes. This advantage was more clearly shown in the summer when it was often considered desirable not to fly some of the machines doped with an acetate scheme until they had been thoroughly dried in the sun, as the fabric, although reasonably tight under more normal conditions, was excessively slack when exposed to the very humid atmosphere. Numerous weathering tests had been made with every known doping scheme and it became very evident that although certain schemes were advertised as being specially suited to tropical conditions, this was far from being a fact under actual test. The speaker then exhibited some slides of fabric parts that had undergone weathering tests. The first showed an aileron from a " Scout " machine that had been in service for two months, having completed 45 hours in the air, and subsequently weathered in an exposed position for nine months. It was doped with P.D.N.12 and V.84. On the same slide was another aileron doped with an " acetate " scheme specially recommended for use in the Tropics; this had been weathered for eight months only. Other slides were shown giving close-up views of the surfaces of both ailerons at the end of that period, and whereas the first was, as far as visual examination was concerned, in perfect condition, the second was quite the reverse, as the aluminium covering was peeling off. This cracking had actually commenced after one month's exposure. After four months, peeling commenced and continued to the end of the eight months. Further detailed tests showed that in the first case deterioration of the fabric was negligible; in the second case very serious. To sum up, there could be no doubt that with the nitro scheme in question better results could be obtained under the conditions specified than with any acetate scheme, and it was clearly shown that fabric so treated would long outlast any machine. Some machines were in

fact in service up to 200 hours and the fabric showed no signs of deterioration whatever.

Colonel V. C. RICHMOND said that Dr. Ramsbottom had given a very valuable paper from the point of view that, whatever his particular ideas might be on all these complex points, he had shown clearly that he had reasons for them, and had gone into those reasons in very great detail. From that point of view the paper was a useful summary of the stage which we had reached. He sometimes wished that other folks had as much backing for their opinions as was indicated in this paper. A good deal of play had been made with a table at the end of the paper because it was not strictly comparative. It dealt with mercerised cotton with nitro dope and linen with acetyl dope, but if those who had criticised the table would read back a little they would see that it was only intended to indicate the difference between the rate of weathering in this country and in Egypt. It did not deal at all with the relative merits of nitro and acetyl dopes, although it did appear, since the mercerised cotton happened to have been put with the linen, and two different dopes were used, that that was conceivable, but he thought they could acquit Dr. Ramsbottom of any malice aforethought in that respect. One speaker had referred to reconditioned dope. He (Colonel Richmond) must say, and he believed Dr. Ramsbottom would be able to bear him out, that there had been no question of reconditioning dope which had what one might call "gone bad" in any way, *i.e.*, had lost its viscosity or had undergone any physical or chemical change. The fact was that there had been a very large accumulation of dopes of all kinds, to different specifications, since the war. All these had had to be examined very carefully. A good many of them had been thrown out—just as many of the acetyl as the nitro—and others, which looked as though they should have either solvent or pigment added in order to bring them up to the modern specification, were treated in that way. The difficulty with regard to all these tests was that they took such a long time, and Dr. Ramsbottom had given a summary probably of the position of the dopes at least 12 months ago, if not two years ago. It was important to remember that the tests occupied such a very long time. One speaker had referred to the question of the modern plasticisers which were coming into use. The difficulty at the Air Ministry was that before expressing any opinion or accepting anything of that kind they must see a weathering test at least comparable with the tests applied to well tried schemes, and provided there was sufficient time to test the materials he did not think one need fear at all that the best one would not be adopted. He (Colonel Richmond) had approached the question of permeability of films by moisture from an entirely different aspect from that adopted by the Author, but it bore very much on the points raised in the paper. He had for many years been endeavouring to find a substitute for goldbeaters' skin by synthetic means, and this involved two particular problems, first, the permeability of synthetic films by hydrogen, and, as it transpired, accidentally; secondly, the permeability of synthetic films by moisture. There was no question that, so far as permeability by hydrogen was concerned, there was a very great difference between various substances, due, no doubt, to the rate of evaporation during drying, the volatility of the solvent, and various other physical properties. Of course, it was well known that gelatine was infinitely superior to any of the celluloses in this respect. He could not find much difference between new cellulose acetate and new cellulose nitrate in that respect, when the film was newly made. The difficulty was, however, that one was working with extremely thin films, much thinner than anything which was used in the covering of aeroplane wings, films of not more than 10 gr. per sq. metre, and it was necessary to spray these films on in some cases. In those cases he was greatly handicapped with the cellulose acetate, because he had not yet succeeded in spraying it on satisfactorily. He did not know whether anybody else had, but he would like to know if they had. The result of the permeability with hydrogen was not very different as between the two, but the

permeability of celluloses by hydrogen was so bad when compared with gelatine that he had had to discard them. Then, if one had to use gelatine, the problem was how to work it. He had worked with a sandwich, containing gelatine in the middle and nitro cellulose or cellulose acetate on either face, but there the difficulty was to maintain the flexibility of the gelatine. The flexibility depended on the hygroscopic nature of the glycerine which was put into it, and it was extraordinary the rate at which the moisture would pass through the surrounding films of cellulose acetate or cellulose nitrate and vary the flexibility of the gelatine. In that respect unquestionably, from the tests on the brittleness of gelatine, the cellulose acetate was far inferior to the cellulose nitrate. Balloons had been made with this type of material, in which the permeability inside and outside had been plotted, and the rate at which water vapour could pass in and out of a balloon of that description, through such a film, was perfectly phenomenal. The problem had been repeated on a full-size airship, the R.33. The problem there was different, however, because there they had goldbeaters' skin, and the problem of the passage of moisture through it was very grave. Curves showed that there was very little lag in the change between the absolute humidity content of the surrounding air and the interior of the gasbag. The passage was very rapid indeed. When it came to the question of sticking a film of anything on fabric, we had the interesting condition which Dr. Ramsbottom had referred to, and which he (Colonel Richmond) believed was overlooked by one speaker, namely, the duplex effect of moisture on the fabric and on the film. Most homogeneous bodies, or semi-homogeneous bodies, would swell with the absorption of moisture. The use of the term "swell" was his way of escaping an actual explanation of what happened, as demanded by one speaker, but it was sufficient to say that when they absorbed moisture they would swell. A twisted yarn would swell so far as the fibres were concerned, but the effect of the swelling, of course, was to reduce the length, and therefore the fabric shrank. That was a very big problem in the case of the manufacture of gasbags. We had the goldbeaters' skin, a semi-homogeneous substance, which always tried to swell on the absorption of moisture. Then we had the fabric, which tried to do the opposite, and the two were constantly at war. If we had a bad adhesive then, in the process of time, the skin contracted and drew the fabric behind it into ridges. The whole of the stress was thrown on the skin, which cracked, and the bags leaked. Moreover, in the English practice, which was very bad, the cotton was kept moist and the skin extremely wet, when applied, so that ever after the skins were trying to shrink and the cotton was trying to expand. The Germans had employed a very ingenious way of getting over that, and that was to make up the skins on a big sheet by themselves and let them dry and shrink, and then stretch the cotton and stick it on to the goldbeaters' skins in the stretched condition. He mentioned that as an instance of the war which was going on continually between a homogeneous substance and a twisted yarn when the one was stuck on to the other. With regard to fireproofing, Colonel Richmond said that, from the airship point of view, the rate of burning of fabric did not interest him at all. If the ship, or any small portion of the envelope of the ship, had caught fire, he would look for the nearest parachute. The rate of burning was a very very secondary matter once the fabric had caught fire, but there was one question he would like to put to Dr. Ramsbottom. When actual fireproofing agents had been employed, so that the flame could not be propagated, but charring could take place, what effect would the wind have in breaking up the surface of the charred fabric, because in an airship it was no earthly good having a fireproof covering if the heat charred it so that the covering fell out in big pieces, and any subesquent flames could get to the gasbags?

Mr. G. PALMER (R.A.E.) said Mr. Barr had called attention to an apparent contradiction in the paper, the Lecturer having declared in one place that nitro dope was the better, and in the other that the acetyl was the better. On reading

the paper carefully, however, it would be seen that in the case where nitro was said to be the better the question was one of tautness only. The Lecturer's remarks as to the greater deterioration with clear nitro dope as compared with acetyl dope was in connection with strength. Reference had also been made to the use of modern softeners instead of the old ones. A great many experiments had been carried out with very many different dopes, but Mr. Palmer considered that the fundamental problem to be looked at—and he submitted that it was the predominating difference between acetyl and nitro dopes—was the question of water absorption, which, in the case of nitro, was about half that of acetyl. Consequently, swelling, to which Colonel Richmond had referred, went on to a greater extent in the case of the acetyl than in the case of the nitro; with swelling, which, of course, tended to reduce tautness, there was softening of the film due to absorption of moisture, which also tended to reduce tautness. With regard to the greater extension of fibres in diameter than in length, he pointed out that it was at low humidities that the dope had the predominating influence on the tautness of the combination. At higher humidities the dope let go and the fabric was then called upon to take the load, at a time when the fabric had not absorbed sufficient moisture to give any great degree of tautness. Referring to the re-conditioning of stocks, he said that this was necessitated by the settling of the pigment. The nitro coverings which had been reconditioned recently had been found to be of suitable viscosity, the deterioration being the settling of the pigments to such an extent that re-mixing of the material was essential.

Mr. R. J. MAY stated that he fully appreciated the value of the paper, and would like to congratulate Dr. Ramsbottom on putting before them figures and details of such an interesting character.

He himself, however, agreed with Mr. Barr's statement that the statistics given did not prove the Lecturer's suggestion that nitro dope was preferable to acetyl dope. Practically all the experiments had been performed with fabric doped with acetyl dope, but it would have been of great interest to have had comparative curves, giving the results of tests with fabric doped with nitro dope. He was under the impression that there would have been some interesting and strange results.

With regard to the question of inflammability, the Lecturer had given quite a number of figures with reference to ignition tests, but in his (Mr. May's) opinion a much more important point was that of flame propagation. The Lecturer had dealt with that in but a very few words, and said that approximately the comparative inflammability of nitro dope and acetyl dope was 2 – 1. He himself had, however, conducted many tests and had found that it was nearer 3 – 1. It would thus be seen that the use of acetyl dope gave passengers quite a considerable amount of time to get out of a crashed plane and get away to safety.

With regard to the question of reconditioning, he would inform them that during the war the Aeronautical Inspection Directorate had laid down a regulation to the effect that nitro dopes, although previously passed for service, must be re-tested after three months in store prior to being sent out for actual use. That provision was made because it was well known that after 3-6 months nitro dopes lost their viscosity, and in this connection the Air Ministry had issued tenders for the reconditioning of quantities of nitro dopes. This reconditioning involved not merely stirring in any pigment which might have settled out, but also entailed the addition of a further quantity of nitro cellulose syrup, in order to give the dope a suitable viscosity for application to the planes.

Mr. A. U. NEWTON, B.Sc., A.I.C., F.C.S., referring to the coloured plates mentioned by the Lecturer, said the absorption spectra had been tested by the photographic method, which method might sometimes lead to erroneous conclusions. For example, in the case of white pigments, they reflected practically all parts of the visible spectrum, but some of them at least absorbed some of the rays

in the ultra violet, and for that reason we got contradictory results on comparing the heating effect of the sun's rays or the mercury vapour lamp on white and aluminium. Thus, if the deleterious rays—the rays which were causing the weakening in the strength of the fabric—were in the infra red, the photographic method of comparing the absorption spectra would give no indication of their presence, while apart from that there was no method, so far as he knew, of estimating the intensity of rays which came in at different wave lengths merely by comparing their photographic effect. We could frequently see that the plate had been affected by a beam of a given wave length, but we could not say that it was five or ten times the intensity of a beam of some other wave length. For that reason he considered that the results that were obtained with glass plates had to be treated with reserve. They gave an idea that the most harmful part of the sun's spectrum lay between the wave lengths 3,900 and 3,100 A.U., but he did not think that this evidence could be accepted as final.

Mr. ODGERS (*contributed*): *Comparison Acetyl and Nitro Cellulose Dopes.*—This comparison seems to be entirely in favour of the nitro dopes. Of especial importance is the statement that 1.5 ozs. per sq. yard nitro dope gives practically equal tautness as 2 ozs. per sq. yard acetate dope, with the added advantages that the nitro dope weathers better and is less sensitive to humidity changes. This alone would seem to rule acetate dopes out, for there can be no possible justification for wasting even 0.5 oz. per sq. yard of covered surface on the weight of any aeroplane.

We are told something in the lecture of the deteriorating effects of the products of hydrolysis of acetate dope, but no figure is given for the products of hydrolysis of nitro dopes.

Is there anything to be said in favour of one or the other class of dope from the point of view of manufacturing a commercially uniform and satisfactory article?

Does the Lecturer definitely associate the more favourable qualities of the nitro dope with its smaller water absorption, or its reduced hydrolysis in the presence of water or with what properties?

Fabric and Pigmented Dopes.—Dr. Ramsbottom recommends highly calendered fabric, and says the adhesion is good even when the dope penetration is small. It would be interesting to know what full-scale evidence there is for this. It has been the experience of Messrs. Boulton and Paul that a good penetration by the dope, a "keying" of the dope film into the fabric, is very necessary to successful results. For this reason, a first coat of clear dope has been used before applying pigmented dopes. For example, the following scheme: One coat clear acetate dope, followed by four coats pigmented acetate dope, gave a covering which, after three years exposure to varying humidity and temperature, is still quite serviceable and apparently unimpaired.

There is to set against this a much less happy experience with khaki pigmented dope applied direct to fabric of the same class.

If it is not the "keying" effect of the first coat of clear that is responsible for this, it must be that the clear ensures a better covering of all fibres than a pigmented used direct possibly can. The results are before us as a good testimonial to acetate dopes and to a priming coat of clear dope.

Aluminium Varnish.—Having regard to the low extinction coefficient for actinic rays of aluminium varnish, and the fact that the cooling due to the aluminium finish is only 10°C., it would be valuable to have it established whether the extra deterioration feared from the temperature rise, is in the fabric and dope or in the structure material of the wings. If the latter, there remains no reason for calling for the aluminium finish on metal wings.

Dr. RAMSBOTTOM, in reply, said with regard to the table at the end of the paper, there was no intention in this table of comparing the weathering qualities of acetyl and nitro dopes. The object was merely to compare the relative weathering effect in Egypt and Farnborough, and the instances given were chosen at random. Throughout the paper there had been no intention of condemning acetyl dope, he had simply given the results of various tests on typical nitro and acetyl schemes. There was one fundamental difference between the two, and that was the water absorption, which must affect tautness. He had tested various kinds of cellulose acetate with all the known softeners, and the difference was so marked that there appeared at present little chance of obtaining cellulose acetate with such a low degree of water absorption as nitro cellulose, although, of course, it might be possible to obtain improved modifications of cellulose acetate. As regards the action of weathering, he believed one could safely say that there was very little difference between fabric protected by nitro dope and by acetyl dope, if the covering was opaque. It was suggested by one speaker that possibly the nitro dope would cause greater deterioration, but that was not so. After weathering for four years there was little difference in deterioration between pigmented nitro and pigmented acetyl doped fabric. As regards the action of acetic acid, as one speaker had remarked, there was very little action when fabric was immersed in acetic acid; it was the action of acetic acid on fabric in the presence of sunlight which was important.

In the comparison of nitro and acetyl dopes for tautness the latest B.E.S.A. schemes were chosen, so that there is no question of dealing with obsolete dopes as suggested by Mr. Cumbers.

With reference to the point raised as to the relative stability of dopes, the stability of acetyl and nitro solutions obviously depends on their composition, *e.g.*, it is well known that certain substances such as tetrachlorethane in the case of acetyl solutions and certain inorganic salts in the case of nitro solutions, cause fairly rapid degradation of the ester, rendering the solutions unserviceable. Further, certain types of esters are themselves relatively unstable. The acetyl and nitro solutions made to B.E.S.A. specifications are, however, extremely stable. We have had similar solutions stored in metal drums since 1915 and they are still in good condition. On the other hand, some of the material supplied as aircraft dopes and varnishes during the war has been found, after several years' storage, to have undergone decomposition. It should be remembered, however, that during the war specifications for dopes and varnishes had to be considerably relaxed, little or no attention being given to keeping qualities. It is interesting to note that the nitro solutions kept better in storage than the acetyl. The percentage of totally unserviceable acetyl solutions being 4.75 times greater than the percentage of unserviceable nitro.

One important point in connection with the deterioration of acetyl and nitro solutions used on aircraft is the different course which the deterioration follows in the two cases. With acetyl solutions the degradation produces a form of acetate of a less degree of solubility, which is thrown out of solution and is not dissolved by any of the usual solvents, so that the product is entirely useless for aircraft purposes. On the other hand, the degradation of nitro solutions usually leads to a product of higher solubility, the viscosity of the solution being diminished. The material can usually be made serviceable by adding more ester.

With reference to Mr. Odgers' remarks on the use of a first coat of clear dope and the adhesion of dope to calendered fabric, better tautness results have been obtained in practice by pigmenting all coats of dope than by using a first coat of clear dope followed by pigmented dope (see Advisory Committee Report, R. and M. 606). The standard practice adopted on Air Force machines as set out in B.E.S.A. specifications is to pigment all coats. This method has been used since 1918, so that there is enough large scale evidence to enable definite

conclusions to be drawn. Incidentally it may be remarked that the pigment has been found to improve the adhesive quality of dope as measured by the tensile strength of joints.

There is ample full-scale evidence to show that fabric in the highly calendered condition gives superior tautness results than fabric in the uncalendered condition; it would be surprising to us if this were not so. Even highly calendered fabric has a comparatively rough surface and the dopes used have good adhesive properties. The dope which escapes to the back of the fabric cannot exert its full tautening power. The deciding test as to whether adhesion is good or bad is the degree of tautness obtained and the extent to which it is retained after long weathering.

By highly calendering the old B.E.S.A. fabric F.1, it was found that a saving of $\frac{1}{2}$ oz. per sq. yd. of dope could be effected without loss of tautness.

The question of cracking of the dope film does not of course arise with pigmented dopes which conform with B.E.S.A. specifications and which are applied under standard conditions to clean fabric. Components are recovered long before the dope layer has undergone sufficient chemical change to break up the film.

An aluminium finish is recommended for metal wings covered with fabric because apart from the temperature effect, better tautness results are obtained in a moist atmosphere after long weathering.

A hearty vote of thanks was accorded Dr. Ramsbottom.

GLIDERS: THEIR HISTORY AND USES

BY W. H. SAYERS.

[*A Paper read before the Royal Aeronautical Society, Scottish Branch.*]

Just a month or two more than twenty years ago, Orville Wright made the first flight on a power-driven man-carrying aeroplane. This original Wright biplane was very far from being the first serious attempt to produce a man-carrying aeroplane, and it is not unfair to say that the machine itself was in its essential principles, and in respect to the skill and ingenuity displayed in its design and construction, no revolutionary advance upon certain previous machines which had been designed for the same end.

As a matter of fact, the machine, including engine, was designed and built in little more than a year, and regarded purely as an engineering structure it was considerably cruder than certain earlier aeroplanes which never succeeded in flying.

The explanation of the Wrights' success in this matter is, I think, to be found in the fact that they had learnt to fly before they attempted to build an aeroplane rather than in any remarkable qualities possessed by the aeroplane which they produced.

Long before the Wright brothers embarked on their experiments men had flown on gliders using gravity as their source of power. For the most part these early gliders were very elementary affairs, depending upon the acrobatic agility of the pilot for control. Nevertheless, they had served a valuable purpose in establishing the possibility of dynamic flight, provided that an engine of sufficiently low weight per h.p. could be produced. Early attempts at producing aeroplanes were largely focussed upon this problem of producing a machine at once sufficiently light and sufficiently powerful to fly. The problem of how these machines were to be controlled if and when they flew was largely neglected by their designers, and there is not the slightest doubt that these early attempts at power-driven flight were foredoomed to failure on that ground alone.

The Wright brothers began their practical experiment with gliders in 1900, and they devoted their attention mainly to the problems of balancing and controlling their machines by methods less crude than that of moving the pilot's weight about the machine. The investigation of these problems led them into many unexpected researches, and by the time that they felt justified in building their first engined machine they were in possession of data bearing upon not only the problems of control, but upon many of the other essential features of a practical aeroplane. Moreover, they had a practical knowledge of how the machine might be expected to behave in the air and what to do with it when it got there.

In very little more than three years from their first active experiment, the Wright brothers had flown a power-driven machine, and of those three years, two were devoted entirely to experiment with gliders.

After an appreciable period, during which rumours of the Wrights' work were generally regarded as American yarns, the French aeroplane enthusiasts began to make short power-driven flights, but it might be said that it was not till Wilbur Wright brought a Wright biplane to France in 1908 and showed how an aeroplane should and could be controlled that flying in Europe developed beyond a stage comparable to that reached by the Wrights in their first power flight five years earlier.

After Wilbur Wright's visit, aeroplane performances in Europe generally advanced at a surprisingly rapid rate, without any commensurate improvement

in the efficiency of the aeroplanes themselves. The Wright brothers, in fact, taught the world to fly, after having themselves found out how to do it by using gliders.

The history of the Wright brothers should be convincing proof of the value of the glider as a method of investigating many of the more vital problems of flight, and it can only be regarded as surprising that so little use has been made of the glider for experimental work since their time. The explanation, I think, is that mainly as a result of the Wrights' work the art of controlling an aeroplane had advanced much more rapidly than did the aeroplane itself, and from 1908 to 1914 the chief problem which engaged our attention was the improvement of the performance of the aeroplane, more particularly by the development of more powerful and more reliable engines. From 1914 to 1918 the demands of war for improved performance were even more insistent, and the development of the wind tunnel method of experiment on models promised to give results bearing on performance problems more rapidly and of a more complete and generally useful nature than could be obtained in any other way.

Whatever the explanation, the fact remains that with the one or two exceptions the example set by the Wrights was not followed by those who continued the work of developing the aeroplane. A certain number of gliders were made both for sporting purposes and with the idea of using engineless machines for preliminary training of pilots, but little success attended these efforts. The Wright brothers themselves continued to use the glider for experiments, including attempts to utilise the energy of the wind to maintain themselves in the air, and in 1911 Orville Wright actually kept in the air for eleven minutes in a wind blowing up the face of a sand dune.

Jose Weiss in this country experimented with an inherently stable type of glider. The experiments originated at a very early date and led to the building of a man-carrying glider in 1909. Flown by entirely inexperienced pilots (Messrs. Gordon England and Leach) these machines made soaring flights of considerable duration, despite the fact that the only control provided was a slight warp of the trailing edge. An attempt to develop this type of machine as an engined aeroplane in 1911 failed from lack of financial support, despite the achievement of a few very promising flights.

The early experiments of Dunne were made with the aid of gliders, and permitted the development of another very novel type of inherently stable aeroplane to be carried to a conclusion. Neither in this case nor in the case of the Weiss type does the fact that the type of machine so evolved has failed to survive imply any reflection on the method of experiment employed, for it is obvious that the attempt to build inherently stable machines of either type with abnormal and unorthodox controls directly in an engine-driven form would have pretty certainly resulted in extremely serious accidents. No such accidents marred the work of Weiss and Dunne.

A certain amount of sporting gliding was carried on in Germany before the war, and in the summer of 1912 a gliding meeting was held in the Rhön Mountains, N.E. of Frankfurt. The machines entered were of very elementary type and nothing of note occurred. It is interesting, however, that entries were made by quite a number of gliding clubs, mostly from German universities. Gliding then suffered extinction until after the war.

In 1920 the Rhön gliding meeting was revived, and some twenty or thirty entries were received. Of the dozen or so machines that actually took part in the meeting, a large proportion were entered by associations of students at German universities. These machines were in general designed by students of aeronautics at those universities and represented distinctly advanced ideas of aircraft design. The actual results achieved were not very startling, but flights up to five minutes'

duration were made and a very considerable degree of interest was aroused, both in Germany and elsewhere.

The results did not end with the close of the meeting. A certain number of the machines entered for the competitions remained at the sheds erected on the top of the hill known as the Wasserkuppe, and experimental gliding was continued by these students' associations and by private experimenters. A school of gliding was established on the spot by a commercial firm which also undertook the building of gliders, and when the time for the 1921 competitions came round there was already in existence at the site of the contests a colony of machines and workers who had behind them considerable experience in the art of gliding.

Despite this, the 1921 meeting produced no results which startled the world. A number of extremely efficient machines were entered, and pilots of skill and experience were present to handle them. The weather conditions were unfavourable for record-breaking purposes, but immediately after the close of the contests themselves, better conditions set in. On August 30th, Herr Klemperer, of the staff of Aachen (Aix-la-Chapelle) University, flew the monoplane of his design entered by the Aachen Students' Association from the sheds on the top of the Wasserkuppe to the village of Gersfeld. The flight took thirteen minutes, the distance along the flight path being some seven miles. The Wasserkuppe is a mountain of some 3,000ft. Gersfeld, the nearest village and the head of the railway line, is 1,200ft. below the summit, which can be reached by foot from the village in about an hour's hard tramp. There is a road practicable for cars and other wheeled vehicles, but this involves a very considerable detour, and Klemperer's flight was made with the object of transporting the machine to the railhead in order to return it to Aachen.

A week later, Martens, on the monoplane of the Hannover University Students' Association, made a flight of a little over a quarter of an hour's duration to another village—Batten—situated somewhat further away than Gersfeld, and again a week later Herr Harth, an independent experimenter, working a few miles away from the Wasserkuppe, flew twenty-one minutes, and, on the following day, twenty-two minutes, landing in the first case within twelve metres of the starting level. In the case of the two flights by Harth, it was claimed that the energy of fluctuating wind was employed, but it is doubtful if this claim can be substantiated.

In the other two cases there is no doubt that the upward component of a wind blowing up the side of a range of hills provided the motive power. These performances led to greatly increased enthusiasm in Germany, and attracted some little attention elsewhere, notably in France.

In 1922 both France and Germany were the scene of gliding competitions. The two meetings coincided in point of time. That held in France suffered from lack of experience leading to the choice of an unsuitable ground, and although the results obtained might fairly be considered encouraging, they were rendered insignificant by the results of the concurrent contests at the Wasserkuppe, where flights of one, two, and finally three hours were made by Martens (of the fifteen-minute flight of the previous year) on the Hannover "Vampyr." During the same period several other German machines made flights of an hour or more. These results startled the world and led to the offer by the "Daily Mail" of a prize of £1,000 for the best British gliding flight of not less than thirty minutes' duration.

At the competition held under the auspices of the Royal Aero Club at Itford Hill in Sussex in October of that same year, the best performances of the German pilots were apparently equalled by both French and British gliders, the "Daily Mail" prize being won by M. Maneyrol with a flight of three hours twenty-one minutes after Mr. Raynham had already flown nearly two hours.

The surprising success of the Itford meeting was, I believe, a most unfortunate event for gliding in this country. The ground chosen for the competition was selected with considerable care after examination of the features of the ground found to be suitable by the Germans, and of the characteristics of the unsuitable French site. In fact, Itford Hill is definitely the best ground for gliding duration records that has yet been used for competition purposes. And by a coincidence hitherto unparalleled in the history of gliding meetings, during the whole period of the contest a strong but just not too strong wind blew from the most favourable quarter.

The result was that machines definitely and markedly inferior in efficiency to the best German gliders were able to make performances more spectacular than those already made by the superior machines. So far as this country is concerned, the result was to lead many people to believe that there is nothing in gliding, that the results obtained in Germany are due to exceptionally favourable conditions at the Wasserkuppe, and that the German performances do not show that German designs are in any way of especial merit.

The effect of Itford on French opinion has been somewhat different. They had learnt the essential features of a good gliding terrain from their own and British experience, and have set about raising gliding duration records—the figure at the moment stands at 8½ hours—by carefully choosing a favourable ground and waiting for the right weather.

In Germany the same lesson as to the predominating influence of ground and wind conditions on the making of duration records has also been appreciated, and Germany has abandoned duration contests for competitions intended more directly to encourage increased aerodynamical efficiency. Of these, that of the maximum distance measured in a straight line from start to finish of a flight has been given the greatest importance and the result is to be seen in the machines entered for the 1923 Rhön Competition.

The main characteristics of the advanced German types—for there are contests designed to encourage training and purely sporting types of gliders—is the determined effort to achieve hitherto undreamt-of gliding angles. It is claimed that at least one of the 1923 machines has a maximum L/D ratio of 21-1—nearly three times the figure advanced within the past few months by a well-known British aerodynamic expert as that which may reasonably be expected of a well-designed aeroplane. There is no reason to doubt the accuracy of this claim, despite the fact that so far no very startling performances have been made by the latest German machines.

The 1923 meeting at the Wasserkuppe was marked by very bad weather. Violent gales were interrupted by calm spells accompanied by rain. One or two attempts to fly in those gales ended in disaster, and consequently very little flying actually occurred at the meeting.

The most noticeable characteristic of the 1923 German gliders was the adoption of very high aspect ratios for the wings. In one case the aspect ratio of a purely cantilever wing was 19-1, and two or three machines approached that figure. There are obvious structural difficulties to be overcome in the construction of machines of such abnormal proportions, and the evidence of 1923 is that these difficulties were not successfully overcome by the German designers, for at least three of these high aspect ratio machines broke in the air during the meeting and one or two other similar failures have occurred since.

Certainly since the 1921 meeting the German gliding enthusiasts have had clearly in view the application of gliding experience to the production of low-powered aeroplanes. Both in France and in England the same line of thought has been followed. In England alone has the light aeroplane supplanted the glider entirely. The results of the British Light Aeroplane Competitions at

Lympne last year were undoubtedly surprising and reflect very great credit on those who designed and built the machines which took part.

The success of the light aeroplane in turn has led to a revision of the ideas of many aeroplane designers as to the scope which exists for aerodynamic improvement in aeroplanes of a heavier type. In addition there is no room to doubt that the light or low-powered aeroplane can serve a directly useful end for training purposes, and even for limited types of transport service in favourable conditions. That gliding experiments have once more served a useful end need not further be laboured.

Unfortunately, in my opinion, there exists in this country at any rate an idea that the utility of the glider has vanished with the production of the practical light aeroplane. The fact that after a negligible amount of gliding experience Britain has succeeded in producing better light aeroplanes than any produced in either Germany or France has been held to confirm this opinion.

It may be suggested, however, that the success of the British light aeroplanes, like the success of the British gliding meeting of 1922, is very largely due to a fortunate chance. In the case of the light aeroplane the extraordinary development of the British motor-cycle engine played a very large part. I do not intend to withhold from the British designers of light aeroplanes the credit which is due to them for having so successfully applied the lessons of glider experience abroad, but it is a fact that the British engines used at Lympne average from about one-half to two-thirds of the weight per h.p. of such engines as have been used for a similar purpose in either France or Germany.

The light aeroplane, it may be admitted, will serve certain experimental ends better than can the engineless glider. It simulates more accurately the conditions which have to be encountered in normal types of aeroplanes; it is independent of hills, and to a large extent of wind and weather, on all of which the glider is entirely dependent; and it can therefore be expected to produce results with less risk of delay than can the glider. For the practical designer who wishes to test a projected design for a new commercial or military aeroplane the low-powered light aeroplane provides a method of obtaining practically full-scale flying tests at roughly the same cost as that of tests of a model in the wind tunnel.

The light aeroplane permits the test to include the effects of the airscrew slipstream, which is impossible in the case of the glider and difficult in the case of the model.

In a lecture recently, Mr. W. O. Manning, the designer of the " Wren " light monoplane, claimed that the light aeroplane superseded the glider as an experimental apparatus.

He pointed out that in the case of the glider the energy required for flight is provided by the wind. Therefore, provided that the L/D could be improved and the wing loading kept the same, the weight of the machine was immaterial. He instanced as an example the enormous aspect ratio of German gliders, to which I have already referred. In the light aeroplane the power is provided by an engine, and the amount of power required depends on the product of weight and L/D. Beyond a certain limit it would not pay to increase the aspect ratio of the light aeroplane because the aerodynamic advantage will be outweighed by the increased weight of the machine. This argument is undoubtedly sound in so far as it bears on the use of light aeroplanes as an immediate aid to practical design of normal types of aeroplanes.

But exactly the same argument may be used to show the value of the glider for experimental purposes. Even the glider represents a fairly complex problem to the designer. It is never possible to attempt to push any one feature in the design to excessive lengths without meeting obstacles imposed by other necessary qualities. Even in the glider it is impossible to pass certain limits of aspect ratio

without reaching impossible structural conditions. In any attempt to reduce the air resistance of a man-carrying machine practical limits imposed by considerations of control, stability, facilities for housing, handling on the ground, the accommodation of the pilot, provision of a satisfactory field of vision, etc., are encountered which entail the sacrifice of obviously desirable aerodynamic qualities.

One can push the glider up more nearly to the maximum of aerodynamic efficiency than is the case with the engine-driven machine because there are fewer limitations to design. It may be asked: "What is the use of that if the same efficiency can never be obtained in a real aeroplane?" The answer is that until we know what can be done when we are free from limits imposed by practical considerations we cannot know how much we are really sacrificing to meet those considerations. Unless we know that we cannot expect to make the best compromise between the various factors involved, and therefore cannot build as good a practical aeroplane as would be possible had we more complete knowledge.

But the glider has fields of its own in which the light aeroplane has no part. It has one very great advantage over the light aeroplane for sporting purposes and that is that its existence was not recognised by those responsible for the drafting of the International Air Convention and that in consequence there are no regulations as to the provision of airworthiness certificates and so forth. It is estimated that the effect on a light aeroplane of having to comply with present Air Navigation Regulations is to double the selling price of the machine.

Given a suitable ground—and at least in the neighbourhood of Glasgow there are plenty of easily accessible sites—a large amount of excellent sport and exercise, together with much useful practice in the art of flying, can be obtained with a most elementary type of glider of the simplest possible construction. With suitable precautions as to the nature of the ground used, this form of flying can be made remarkably safe, and the development of gliding of this type offers a means of educating the rising generation in the essentials of flying which cannot be equalled by any other known means.

It is objected that gliding as a sport consists of too much hauling of the glider up the hill and of too little gliding. I have no evidence that shows that skiing and bobsleighing as sports are dying out, and the objection applies equally to these mainstays of the Swiss hotel proprietor. What is a fact is that gliding is not a sport which can be carried out with any satisfaction by isolated individuals. Regularly established gliding centres and some sort of club organisation are necessary, but given those conditions I am convinced that gliding has immense possibilities. In London and the South of England generally it is difficult to find really good grounds except far away from populous centres, and this makes difficult the establishment of gliding clubs. From my recollections of the country round Gasgow I imagine that conditions are much more favourable here, and the University and the Technical College might do worse than to form gliding clubs such as are to be found attached to practically every German "Technical High School."

Apart from the use of quite elementary gliders suitable for training and purely sporting gliding, there is room for a large amount of highly interesting experimental work. The flights already achieved in Germany, England and France have proved the possibility of maintaining prolonged flights in a wind having an upward velocity such as may be found over the windward slopes of quite small ranges of hills. Flight of this type is dependent on the presence of the hill and of a wind from the right quarter. The distance that can be covered from point to point in such flights is determined firstly by these physical conditions, but also to a very large extent by the efficiency of the glider and by the skill of the pilot. At the Itford meeting in 1922 it was evident that with most inadequate controls and with relatively inefficient machines, there was no difficulty in flying up and down the unbroken range of hills for an indefinite period. But to have jumped the gap

from the western end of that range to the eastern end of the succeeding range where level flight could have been continued probably for another twenty miles would have called for better gliders and more experienced pilots than were available at that time.

Personally, I am convinced that very much more can be done in the way of gliding long distances over country such as may be found all over Great Britain than is generally supposed, and that long-distance gliding has immense sporting possibilities. I am glad to know that at least one Scots enthusiast is of the same opinion, and that he hopes to make an attempt to win the Selfridge 1,000 guineas prize for a fifty-mile glide during this year.

There are other gliding possibilities of flying by wind energy than those offered by upward currents produced by surface gradients. Up to the present these have not been adequately explored. Winds in practice are never steady or uniform in direction, and that being the case it is possible to obtain energy from winds that are not as a whole directed upwards. The simplest method by which energy may be taken from a variable wind is one which has been attempted in Germany—it is said with some success. If a machine flying at a steady air speed meets a head-on gust, owing to the inertia of the machine the air speed will tend to increase and the machine will climb. After a period the machine will resume its original air speed but at a greater altitude than it would possess had it not encountered the gust. If the gust is succeeded—as it invariably is—by a fall in the wind velocity, and if just as this negative gust begins the machine can turn 180 degrees and fly down, wind inertia will again cause the machine to lag in its readjustment of speed and it will again climb.

Theoretically, the process could be repeated indefinitely so long as a gusty wind continues. Practically there are certain difficulties, not the least that of foreseeing changes of wind velocity in time to manœuvre the machine to suit. Also even if this form of flight can be achieved, the flight path of the machine will be a series of loops, and progress over the ground will be dictated by the direction and average velocity of the wind.

It can be shown that rapid fluctuations of wind velocity quite independently of any special manœuvring of the machine provide a source of energy for an aeroplane flying in that wind. If the wind is rigidly horizontal this energy, however, is supplied in a form which is of but little real value for gliding purposes —it slows up the rate of descent of the glider but it cannot maintain it in level flight.

If the variation in velocity is accompanied by changes in vertical velocity—that is, if a fluctuating wind consists of alternate gusts directed slightly upwards and slightly downwards—then, as Prof. Koller of Vienna has demonstrated mathematically and Prof. Betz of Göttingen has verified experimentally, it is possible for the resistance to forward movement of an efficient wing not merely to vanish but to be changed into a positive thrust.

In a wind of this type a glider should be able to maintain its altitude and even to climb. At present we do not know to what extent winds ordinarily display this form of fluctuation, and how much of the available energy can be extracted from such winds by a practicable glider. Some preliminary experiments on gliding in fluctuating winds have been carried out in Germany, and it certainly seems a subject worthy of further investigation.

It is quite probable that the glider may never be a practically useful form of transport. On the other hand it is not impossible that in certain parts of the globe flight by the use of the internal energy of the wind may have a limited practical utility.

But what is quite certain is that every increase in our knowledge of the phenomenon of flight will in time serve a useful purpose. For although a source

of energy such as that provided by the wind may never be sufficient to allow regular flying without an engine, it is even now possible to use the result of gliding experience to improve the performance of the engined aeroplane. Mr. Raynham some time ago proved that by flying along over the windward slope of the South Downs in a moderate wind the level speed of a Vickers Viking amphibian was increased by over 15 m.p.h. for the same engine revolutions. In the Grosvenor Cup Race last year the same pilot flew over a circuit of 400 miles on an Avro at an average speed (96 m.p.h.) much in excess of the maximum level speed of the machine under test conditions, and he states that some at least of this increased speed was obtained by choosing a flight path such that whenever possible he was flying in up-currents. It is obvious that wind energy which is insufficient for level flight is nevertheless energy, and that under favourable circumstances even heavily-loaded commercial aeroplanes can use such energy to increase their speed without any corresponding increase in their fuel consumption. Therefore quite apart from any prospect of developing gliders to useful purpose, investigation of the problem of gliding will serve to make possible a better use of normal type aeroplanes.

REVIEWS

The Internal Combustion Engine

Volume II. High-Speed Engines

By Harry R. Ricardo, B.A., A.M.Inst.C.E., M.I.A.E. Blackie and Son, Limited. Price 30/-.

The second volume of Mr. Ricardo's treatise on the "Internal Combustion Engine" deals with high-speed petrol engines. The first two chapters contain an interesting account of the exhaustive series of experiments undertaken by him and his colleagues for the Asiatic Petroleum Company on the properties of various volatile liquid fuels. It is shown how the maximum efficiency obtainable with any given fuel depends mainly on its tendency to detonate, which limits the degree of compression at which it can be used. Apart from this, accurate experiments have shown, in accordance with theory, that at any given compression ratio the maximum power and thermal efficiency obtainable is practically independent of the nature of the volatile hydrocarbon fuel employed; while the high latent heat of other possible fuels, such as alcohol, causes an increase both in efficiency and power. Not the least valuable part of these researches was the demonstration how, by taking proper precautions, it was possible to design a high-speed engine capable of giving experimental results of a high order of accuracy over a long period of time. For this demonstration, and for his design of other research apparatus, the scientific world is greatly indebted to the author. Chapter III. deals with the distribution of heat in a four-cycle engine, and the effect of cylinder size on power and efficiency. Chapters IV. to IX. inclusive are devoted to the consideration of the design of all the important parts of a high-speed engine, and of problems of lubrication and carburation. They contain in a small compass the conclusions drawn from a wide experience and from a large number of experiments, and the data provided will be of considerable value to other designers. Chapter X. contains a particularly interesting analysis of the factors governing the performance of motor cars, together with details of the 14 h.p. Vauxhall engine and the three-litre Vauxhall racing engine. A description of modern aircraft engines, and a discussion of the problems associated with the design of aircraft engines for use at great heights is contained in Chapter XI., while the final chapter is devoted to an account of the high-speed Ricardo tank engine.

The book is in no sense a text-book; nor does it pretend to be a complete survey of all modern work on high-speed engines. The literature of the subject is now so immense that it would tax anyone's powers to condense it into a single volume. Mr. Ricardo has wisely not made the attempt, but has restricted himself mainly to those aspects with which he has been most closely concerned. He and his colleagues may be justly proud of the quality and quantity of their work, of which this book is a fascinating record.

The International Air Congress Report, 1923

The meeting of the International Air Congress in London last year was a very real success. The volume containing the proceedings has now been published and it would be hard to find a better illustration than it affords of the numerous compartments into which the good ship "Aviation" is divided. For this reason alone the book should be studied by all who are interested in flying. There are other reasons, too—the specialist will be certain to find something of

interest along the lines of his work; but apart from that it is important for workers in any one field to know something, at any rate, of what is going on in the adjoining fields. This neighbourly information can be obtained from the present volume in a way which proved quite impossible during the Congress itself. At the Congress there were simultaneous sittings—much as at meetings of the British Association—and it was physically impossible for any member, if at all catholic in his tastes, to attend all the discussions at which he would have liked to be present. To the bound volume he must accordingly refer and, unless his mental make up is very different from that of the reviewer, he will be surprised to find how much was going on at the Congress in which he, however willing, was unable—by reason of the difficulty of being in two or more places at the same time—to take any share. Sections of the book are concerned with the organisation of research, others with aero engine problems, with aerodynamic theory, navigation, surgery, meteorology, "air" law, civil aviation, the chemistry of fuels, the strength of materials. And all of it thoroughly well knit together and reflecting credit on the editorship and general organisation.

Confidential work of a military character was of course excluded—from the purely scientific point of view this was a pity, but of course quite inevitable. Had this limitation not existed the variety of the subjects dealt with would have been even more impressive and the 900 pages of the present volume would have had a most remarkable accession. This invisible addition to the visible pages must be read with the eye of imagination.

H. E. W.